GRADUATE PROGRAM

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

COLLEGE OF ARCHITECTURAL AND CIVIL ENGINEERING

ASSESSMENT OF MARBLE WASTE POWDER IN ASPHALT CONCRETE MIXES AS A FILLER PARTICULARLY IN TIGRAY REGION

(MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT)

By

KINDE WORKU

A Thesis Submitted to College of Architectural and Civil Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Construction Technology and Management)

ADVISOR

MELAKU SISAY (PhD)

June, 2017

ADDIS ABABA, ETHIOPIA

APPROVAL PAGE

This Msc thesis is entitled to **"ASSESSMENT OF MARBLE WASTE POWDER IN ASPHALT CONCRETE MIXES AS A FILLER PARTICULARLY IN TIGRAY REGION (MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT)"** has been approved by the following examiners in Partial fulfillment of the requirements for the degree of Master of Science in Construction Technology and Management.

Date of Defense: June 03, 2017

Principal Advisor:

1. Dr. Melaku Sisay ________________ ________________
   Signature Date

Members of Examining board:

1. Dr. Girmay Kahsay ________________ ________________
   External Examiner Signature Date
2. Dr. Brook Abate ________________ ________________
   Internal Examiner Signature Date
3. Mr. Simon G/Egziabher ________________ ________________
   Head, Civil Eng'g Department Signature Date
4. Dr. Brook Abate ________________ ________________
   Dean, College of Architecture Signature Date
   and Civil Engineering

I, the under signed, certify that I read and hear by recommend for acceptance by Addis Ababa Science and Technology University a thesis entitled **"ASSESSMENT OF MARBLE WASTE POWDER IN ASPHALT CONCRETE MIXES AS A FILLER PARTICULARLY IN TIGRAY REGION (MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT)"** in Partial fulfillment of the requirements for the degree of Master of Science in Construction Technology and Management.

____

Dr. Melaku Sisay

Principal Advisor

DECLARATION AND COPY RIGHT

Kinde Worku Kebede, Declares that this thesis is my original own work that has not been presented and will not be presented by me to any other University for similar or any other degree award.

____

Signature

ACKNOWLEDGEMENTS

First of all, I praise to GOD for giving me endurance and patience to cope all the ups and downs throughout the studying period.

I sincerely thank Dr. Melaku Sisay for his supports, guidance, suggestions, encouragements and valuable comments during the research.

I also would like to express my sincere thanks to Ethiopian Road Authority for giving an opportunity to study in post graduate program, Addis Ababa Science and Technology University for financing half of my thesis budget, Maytsebri – Shire Road Upgrading Project contract - II for allowing me to do tests in its laboratory, and Saba Dimensional stone factory for giving me Marble waste free of charge for the research.

My profound gratitude goes to Ato Alemayehu Asfaw, the project manager of Maytsebri – Shire Road Upgrading Project contract - II for allowing me to spend my time in the project laboratory for the research.

My especial thanks also goes to Ato Tessema Amenu, a worker in Maytsebri – Shire Road Upgrading Project contract - II laboratory, for his invaluable and kind support during tests.

I am thankful to all my friends especially Freezer Mohammed, Anwar Mohammed, Mahder H/Silassie, Kalu Teferi and Emawayish Tsegaye for their material and moral support.

Lastly I am thankful to all my family members in general and particularly Yetemegn Taye, Eyerusalem Misker, Workafus Endale, my mother and my father.

KINDE WORKU

Addis Ababa, Ethiopia

June, 2017

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

AASHTO	American Association of state High way and Transportation officials
ACV	Aggregate Crushing Value
Al_2O_3	Aluminum Oxide
ASTM	American Society for Testing Materials
CaO	Calcium Oxide
Cm	Centimeter
Cm^3	Centimeter cube
Cm^2/ g	Centimeter Square per gram
CO_2	Carbon Dioxide
EAPA	European Asphalt Pavement Association
E.C	Ethiopian Calendar
EN	Euro Norm
ERA	Ethiopian Road Authority
ES	Ethiopian Standard
Fe_2O_3	Iron Oxide
Fig	Figure
gm	Gram
Gb	Specific gravity of Asphalt
Gmb	Bulk Specific gravity
Gmm	Maximum Specific gravity
Gsb	Bulk Specific gravity of Aggregate
Gse	Effective specific gravity of Aggregate
HMA	Hot Mix Asphalt
In	Inch
Kg	Kilo gram
Kg / cm^3	Kilogram per cubic centimeter
Kg / m^3	Kilogram per cubic meter
Km	Kilo Meter
Km/hr	Kilo meter per hour
KN	Kilo Newton
LAA	Los Angeles Abrasion

LOI	Loss on Ignition
m / s	Meter per second
m^2	Meter Square;
m^2 / Kg	Meter square per kilogram
m^3	Meter cube
MgO	Magnesium Oxide
mm	Millimeter
MnO	Manganese Oxide
Mpa	Mega Pascal
MS	Manual Series
Na_2O	Sodium Oxide
NW	North West
P_b	Asphalt content, percent by total weight of mix
P_{ba}	Absorbed asphalt , percent by weight of aggregate
P_{be}	Effective Asphalt content
Pmm	Percent by weight of total loose mixture
PPC	Portland Pozzolana cement
P_s	Aggregate content , Percent by total weight of mixture
RMA	Recycled marble aggregate
Sio_2	Silicon Dioxide
SW	South west
TLTM	Tanzania laboratory testing manual
TFOT	Thin Film Oven Test
Va	Air voids
VFA	Voids filled with asphalt
VMA	Voids in the mineral aggregate
Wt	Weight
%	Percent
o_C	Degree centigrade
µm	Micrometer

ABSTRACT

Marble waste has been used in high way construction as a filler substitute in hot mix asphalt paving. Many countries have recently incorporated marble waste powder in to their road way specifications, which had encouraged greater use of the material. The main objective of this research is to investigate the use of marble waste powder as a filler in hot mix asphalt; and specifically to study the effect of adding different percentages of marble waste powder on the properties of asphalt mix comparing with conventional mix properties by Marshal test, and identify the optimum percent of marble waste powder to be added in the hot mix asphalt. In this research a number of aggregate and bitumen tests are conducted to investigate the applicability of using marble waste powder as a filler in hot mix asphalt concrete. Marshal samples are prepared using both aggregates and marble waste powder to investigate the properties of the asphalt mix. By using Marshal Mix design procedure, fifteen hot mix asphalt mixtures with three types of mineral fillers and four proportions of marble waste powder by weight of aggregates were prepared. For each filler content, four hot mix asphalt concrete were prepared. The results showed that it is possible to use the marble waste powder in preparing hot mix asphalt concrete. Marble waste powder contents 2%, 2.5%, 3% and 3.5% with 4.82% bituminous binder and 2%, 2.5% and 3% marble waste powder contents with 4.97% of bituminous binder satisfy the specified requirements of Maytsebri – Shire road upgrading project specifications limit. Marble waste powder content of 2% by weight of aggregate with 4.82% optimum binder content and 2.5% marble waste powder content with 4.97% optimum binder content have higher stability value. The results of this research work is hoped to be used as the basis for further investigation on the effects of mineral fillers and improve asphalt concrete as well as find alternative materials.

Key words*: - Marble, Cement, Marble waste powder, Filler, hot mix asphalt mixture*

CHAPTER ONE
INTRODUCTION

1.1. General

The government of Ethiopia has allocated a huge amount of resources to upgrade the existing road network nationwide. In connection to this, nowadays in our country most of the trunk, link roads and some economically sensitive area roads are constructed and rehabilitated using asphalt concrete (Anteneh, 2014).

Traditionally soil, stone aggregates, sand, bitumen and cement are used for road construction. These natural materials are non – renewable and also the cost of extracting good quality of material is increasing. Concerned about this, alternative materials for high - way construction must be sought; and industrial waste products are one such category. If these materials are suitably utilized in highway construction, the pollution and disposal problems are partly reduced.

Mineral fillers consist of finely divided mineral matter such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, marble waste powder or other suitable mineral matter. Mineral fillers serve a dual purpose when utilized in asphalt mixes. The portion of the mineral filler that is finer than the thickness of the asphalt film and the asphalt cement binder form a mortar or mastic that contributes for improving stiffness of the mix. The particles larger than the thickness of the asphalt film behave as mineral aggregate and hence contribute to the contact points between individual aggregate particles. The gradation, shape, and texture of the mineral filler significantly influence the performance of hot mix asphalt.

Nowadays, asphalt concrete mix ingredients with Portland cement is probably the most widely used man made material in the world. Despite this fact, Asphalt concrete mix production is one of the concerns worldwide that have impact on the environment with major problem being global warming due to Co_2 emission during the production of cement. It is estimated that cement production is responsible for about 3% of the global anthropogenic greenhouse gas emission and for 5% of the global anthropogenic Co_2 emission (Tarun, 2005). As about 50% of the Co_2 released during cement production is related to the decomposition of limestone during burning, mixing of clinker with supplementary materials called blending is considered as a very effective way to reduce CO_2 emission (Tarun, 2005).

The technical importance of using wastes and by - products in asphalt concrete production is expressed by performance improvement of asphalt concrete. The economic benefit involves in the reduction of the amount of expensive and or scarce ingredients with cheap materials. Environmentally, when industrial wastes are recycled, not only the CO_2 emissions reduced, but also residual products from other industries are reused and therefore less material is dumped as landfill and more natural resources are saved (Fennis, Walraven, A.den uij, 2009).

Previous study on the Marble waste powder which is a by - product of Marble processing factory was studied by many researchers in the literature review for its use in asphalt concrete, concrete and mortar production as sand or cement replacing material. Most researches showed positive results and benefits. However as the by - product i.e. the powder differs chemically depending on the parent marble rock which depends on the locality, degree of metamorphism and other factors: and also as the physical characteristics of the powder depends on the polishing work.

1.2. Statement of the Problem

Researches in the literature review show that modification made regarding the ingredients of bituminous mixtures such as type of ingredient materials and relative proportion has altered. Some studies in the literature review proved that mineral fillers have indispensable role in the performance of hot mix asphalt. Depending on the filler characteristics, it was found that their purpose was not only to fill the voids but also modifying the mixture.

In the construction of highway pavements, one of the main problem is insufficient amount of crusher dust from crushing of aggregates. Crusher dust also known as stone dust is the most commonly used filler in bituminous construction in Ethiopia. Moreover, there is also environmental deterioration resulting from blasting of more quarry areas to produce the required amount of mineral filler and its mode of production is expensive. Therefore, it is important to see an alternative mineral filler material. Thus, this study was conducted with this intention.

1.3. Justification for the research

Two types of by – products are obtained in marble production. During marble production, 30% of the stone (in case of unprocessed stone) goes to scrap Gammal, Ibrahim, A.Badr, A.Asker and Galad (2011) because of being smaller size and / or irregular shape. This is then sold to manufacturers. In case of semi - processed slab, the scrap level reduces to 2 – 5%. The other waste material is slurry, which is mainly water containing marble powder.

In Ethiopia 209,803m^2, 128,918m^2, 344,452m^2, 161,002m^2 and 200,408 m^2 of marble commodities were produced in the year 2002, 2003, 2004, 2005 and 2006 respectively, According to Central Statistical Agency (2007), which implies that 20 - 30% of this mineral was lost as waste. Currently the amount of loss as waste is increasing due to joining of other companies to the industry.

Saba Dimensional Stone Factory is one of the largest marble processing plant in Ethiopia found in Tigray region. It is located near the areas where human lives. It deposits it's by - product there.

In addition to loss, disposal of this waste material will cause the following environmental problems (Shahzada, Bashir Alam, Bilal, Mushtaq Zeb and Akbar, 2016):

a) If the waste is disposed on soils, the porosity and permeability of topsoil will be reduced, the fine marble dust reduces the fertility of the soil by increasing its alkalinity.
b) When the waste is dumped and dried out, the fine marble dust suspends and pollutes the air.
c) When dumped along a catchment area of natural rainwater, it results in contamination of over ground water reservoir and also cause drainage problem.

Therefore, this is to study the use of marble waste powder in the road construction industry to address environmental problem due to the waste and for efficient use of natural resources.

1.4. Research objectives

1.4.1. General objective

To investigate the use of marble waste powder as a filler in hot mix asphalt.

1.4.2. Specific objectives

1. To investigate the effect of adding different percentages of marble waste powder on the properties of asphalt concrete mix comparing with the conventional mix properties by Marshal test.
2. To identify the optimum percent of marble waste powder to be added in the hot mix asphalt.
3. To experimentally investigate the effect of marble waste powder on hot mix asphalt using Marshal Mix design.

Furthermore, as part of the research objectives, the thesis will draw conclusions and forward recommendations based on the research finding and indicate areas for further study.

1.5. Scope of the study

The research reported was focused on hot mix asphalt characteristics of the Marshal properties such as Air voids (V_a),Voids in the mineral aggregate (VMA), Voids filled with asphalt (VFA) , marshal stability and flow of asphalt concrete produced by marble waste powder. The material selected for this ;study was collected from different sources, i.e. aggregate from Maytsebri - Shire road upgrading project crusher site located at the entrance of Indabaguna town (About 7km from Shire town) and Marble waste powder (slurry form) from Saba dimensional stone processing factory pit located at Adwa (about 81km from Shire town).

The mixtures were prepared using marble waste powder with different amount. The results produced in this research were based on the Marshal Mix design procedures.

1.6. Structure of the Research

The research paper has five chapters and sixteen appendices that discuss various aspects of hot mix asphalt related to relevance of the thesis.

Chapter one: Explains the background and the objectives of the research.

Chapter two: Describes literature review which provides a general understanding of previous studies and theories related to the research.

Chapter three: Discusses the properties of materials and methods used in the research.

Chapter four: Shows the analysis and discussion of the results obtained from the study.

The fifth chapter draws conclusions from the research and provides recommendations. Different data are presented in the Appendices.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Asphalt concrete is a mixture of binder, aggregate and air in different relative amount that determine the substantial properties of the mix. The stability of asphalt mixture is influenced by several features together with gradation of aggregates and type and amount of filler materials. Filler acts as one of the major constituents in asphalt concrete mixture. Fillers not only fill voids in the coarse and fine aggregates but also affect the aging characteristics of the asphalt mix.

During the past years, asphalt concrete technology has attained a lot of achievements. One of the achievements is the incorporation of industrial wastes as a filler in asphalt concrete production with technical, economical and environmental advantages.

Various studies have been conducted on the properties of HMA using minor changes on the ingredients of the mixture. In general the main objectives of the researches were to understand in a better way the characteristics of bituminous mixtures and evaluate the effects of ingredients on the performance.

Among the various studies conducted, many were concerned with the investigation of effects of aggregates in asphalt performance. These aggregates make up 90 to 95 percent by total weight of the mixture. They are the main in influencing the performance of the mixture.

The research concentrates and builds on the Marshal properties of hot mix asphalt mixtures prepared using various replacement rate of marble waste powder on hot mix asphalt concrete.

In this chapter, review of researches conducted on the effect of mineral fillers on hot mix asphalt performance will be discussed.

2.2. Marble

2.2.1. Marble Definition

Marble is a crystalline, compact variety of metamorphosed limestone transformed through the heat and pressure into a dense, variously colored, crystallized rock. It is predominantly composed of calcite with minor impurities. Pure calcite is white in color. Iron and magnesium and some silicate minerals give a significant green color; graphite gives dark, pyrite greenish grey and hematite color marble pink. Some rare colors like sky - blue are due to impurities or “failure” within the calcite crystals (Heldal and Walle, 2002 and ministry of mines).

Manufacturing process of Marble

The manufacturing process of marble involves cutting and finishing marble obtained from quarries, where specific dimensional marble is prepared for various uses in specialized mills equipped with saws, polishing machines, and others. Marble sawing equipment includes large circular saws, where various types of diamond and other equipment are used for smoothing, polishing, and edging the raw marble. The marble production process includes several steps. Marble blocks are cut into smaller blocks in order to give them the desired smooth shape (Gammal, Ibrahim, A.Badr, A.Asker and Galad, 2011).

The processing of marble dimension stones essentially involves the following three major operations. Cutting of marble blocks into a number of small size blocks by heavy duty; cutting machines such as gang saws and diamond saws. Shaping of smaller size marble blocks by equipment’s like planers and turning lathes; and Surface finishing or polishing of shaped marble blocks by rubbing beds and polishing machines in order to attain attractive color and uniform texture.

Environmental concerns in Marble production

The impact of marble manufacture can be estimated and evaluated according to production stage or process. Each process includes some action that adversely affects the environment through one or more environmental norm. For example the sawing or cutting phase involve noise effect and dust emission, while cutter and polishing phases involve chemical uses and contamination of water. However, this waste if dumped will in addition to loss, raising the following environmental concerns (Aukour and Mohammed, 2008).

- Marble companies had a permanent negative impact on land use leading to the loss of ecological habitats with negative effects on flora and fauna populations by reducing the green - agricultural spots and might increase the risk of agricultural contamination.
- If the waste is disposed on soils, the porosity and permeability of topsoil will be reduced, the fine marble dust reduces the fertility of the soil by increasing its alkalinity.
- When the waste is dumped and dried out, the fine marble dust suspends in the air and results in air pollution.
- Ground water pollution results when dumped a long catchment area of natural rain water, it attributes in contamination of over ground water reservoir and also cause drainage problem.

2.2.2. Properties of Marble

2.2.2.1. Chemical Properties of Marble

The rock marble is metamorphosed limestone. It is composed largely of the mineral calcite (Calcium carbonate). It will thus behave like limestone - giving off Co_2 when in contact with hydrochloric acid. It will also give off Co_2 when ground down to a powder and heated to high temperatures (Origlieri, 1998).

Marble forms when limestone deposits are subducted under the earth's crust. Here heat and pressure compress the limestone into marble. Limestone is formed as an accumulation of tiny fossils which pile up underwater and become compacted. The shells are composed of Calcium carbonate. This material is mostly insoluble, but it contributes most of the mineral content to "hard" water. Calcium carbonate reacts with acids to form Calcium ions, carbon dioxide and water. The marble statues in many European cities are being slowly decomposed by nitric and sulfuric acids due to automobile emissions (Origlieri, 1998).

Chemically, they are crystalline rocks composed predominantly of calcite, dolomite or serpentine minerals. The other minor constituents vary from origin to origin.

Table 2.1: Typical Chemical properties of marble (Origlieri, 1998).

Chemical	By percent
Lime (CaO)	28 - 32%
Silica (SiO_2)	3 - 30% (varies with variety)
Alumina (Al_2O_3)	1- 4%
MgO	15 to 25%
FeO + Fe_2O_3	1 - 3%
Loss on Ignition (LOI)	20 - 45%

2.2.2.2. Physical Properties of Marble

Physically, these are re - crystallized, compact, fine to very fine grained metamorphosed rocks capable of taking shining polish (Origlieri, 1998).

Table 2.2: Typical Physical properties of marble (Origlieri, 1998).

Properties	
Hardness	3 - 4 on moh's Scale
Density	2.55 - 2.7 Kg/cm^3
Compressive Strength	70 - 140 N/mm^2
Modulus of Rupture	12 - 18 N/mm^2
Water Absorption	Less than 0.5 %
Porosity	Very low
Weather Impact	Resistant

2.2.3. Uses of Marble

Marble is crushed and used as an aggregate in highways, railroad beds, building foundations and other types of construction. It is also cut into pieces of specific size to produce dimension stone. These are used in monuments, sculptures, and other projects (Peter, 2005).

Marble can be polished to a high luster. This allows attractive pieces of marble to be cut, polished and used as floor tiles, architectural panels, facing stone, window sills, stair treads, columns and many other pieces of decorative stone (Peter, 2005).

Production of Marble, as Dimensional Stone, in Ethiopia

The term dimensional Stone is defined as, "a natural building stone that has been selected cut and trimmed to specified shapes or sizes with or without one or more mechanically dressed surfaces". The definition applies to rough blocks, slabs and polished material used in building, construction and monuments industries. Stones that are finished to specific size and shape are considered as dimension stone. It can be defined as natural rock material quarried for the purpose of obtaining blocks or slabs that meet specifications as to size and shape (Sentayehu, 2011).

Dimension stone, sometimes called ornamental stone for the basic reason that it gives a romantic beauty to the fascinating architects of modern buildings. Color, grain size, texture and pattern, and surface finish of the stone are normal requirements. Durability, strength, and the ability of the stone to take a polish are also other important selection criteria (Sentayehu, 2011).

Marble, granite, limestone, and sand stone provide the bulk of dimensional stone: although slate, diorite, basalt and diabase are included. The classification of dimension stone is not strictly adhered to sedimentary, igneous and metamorphic grouping of geology, as the stone trade name under "granite" refers to all true granite and gabbro, norite and syenite. Likewise, all crystalline limestone, travertine, sandstone and serpentine that are capable of taking a polish are grouped under marble in addition to the true marble (Sentayehu, 2011).

Geology of Dimension stone in Ethiopia

A wide variety of rocks are used as dimension stone in Ethiopia. The Precambrian metamorphic and igneous rocks comprise potential resources including marble and granite. These rocks are exposed in the east central (Harar), west central (Gojam and Wellega), north (Gondar and Tigray) and southern (Sidamo, Bale and Illibabore) parts of the country (Sentayehu, 2011).

Most of the exposures are found in the peripheral regions, where younger rocks have been removed by erosion. Extensive deposits of marble occur in Kelafinos, Newi, Ende - tukrir, Naeder and Berdada (Tigray); Baruda, Mora, Daleti, Ganzi, Mankush and Bulen in Benishangul Gumuz Regional state (Sentayehu, 2011).

A variety of igneous rocks, predominantly granites of Proterozoic to early Paleozoic age, occur as intrusive bodies within the Precambrian metamorphic. Some of these have been emplaced prior or simultaneous to tectonometamorphic events, others postdate these events. Deposit of such types occurs in Dehan and Angerguten in west, Babile in east, Meleka in south and north Negash in northern parts of the country (Sentayehu, 2011).

Table 2.3: Dimensional Stone producing companies in Ethiopia

No.	Name of Company	Estimated annual production (m^2)	Type of Stone Processed
1.	National Mining corporation	250,000.00	Marble, limestone and granite
2.	Saba Dimensional Stone factory	180,000.00	Marble, limestone and granite
3.	Ethiopian Marble Processing Enterprise	150,000.00	Marble and limestone
4.	Berta Marble	25,000.00	Marble and limestone

2.2.4. Marble deposit in Ethiopia

The marble deposits of Ethiopia have been known and exploited for many years. Marble is essentially found in the western part of the country, in Gojam and Welega. Deposits also occur in the Tigray region North of Adwa, Shiraro, Abergele, etc. The marble deposits cover large areas, but their quality varies considerably (Heldal and Walle, 2001).

Most of the marble deposits found in these areas are hill forming, others have a flat, though well exposed, morphology, predominantly ,the marbles are calcitic, but white to grey dolomite, occurs as layers within the calcite marbles or as bordering units (Heldal and Walle, 2001).

Several types of commercial marble occur in the area. These include fine - to medium grained, graphitic grey marble with white bands, medium - to coarse grained white marble with grey bands and several subordinate types such as pink, silicate - rich marble, purple white, fine grained marble and sky blue to green marble. The latter two types seem to be connected to contact metamorphic aureoles around gabbroic intrusions. Grain - size varies from fine - to coarse - grained (Heldal and Walle, 2001).

Marble deposit of northern Ethiopia is different from that of the west. Except the age, the grain size and color are different. It is fine grained in appearance closer to the originated limestone. These variations are accounted for the low degree of metamorphism white, yellow and violet varities of colors are common (Sentayehu, 2011).

Table 2.4: Marble deposit in Western Ethiopia (Sentayehu, 2011; Heldal and Walle, 2001)

No.	Name of Marble	Location	Estimated Deposit
1.	Bapuri Marble	Metekel zone, 600km west of Addis Ababa.	Several million
2.	Mora Marble	Metekel zone, 595km west of Addis Ababa.	$64.55*10^6$ tons
3.	Bulen Marble	Bulen town, 580km west of Addis Ababa.	$24.51*10^6$ tons
4.	Ekonte Marble	Baruda town,605km west of Addis Ababa	$4.98*10^6$ tons
5.	Tulu - Moye Marble	Baruda town,610km west of Addis Ababa	$6.27*10^6$ tons
6.	Daleti Marble	Daleti town,635km west of Addis Ababa	$2.8*10^6 m^3$
7.	Mankush Marble	Guba town,705km west of Addis Ababa	Several million

Marble deposit in Northern Ethiopia

The marble deposits of Northern Ethiopia occur within the Arabian - Nubian shield, and have a tectonic setting similar to the western and south - western Ethiopia, with in successions of Meta - volcanic and Meta - sedimentary rocks of upper Proterozoicage, which are intruded by basic to acidic intrusions. However, since the metamorphic grade in the marble is lower than farther to the south, the marbles of northern Ethiopia appear more fine - grained. The basement rocks constitute about 68% of the total surface area of the region (Heldal and Walle, 2001).

There are several marble processing plants in Ethiopia; Saba Dimensional Stone factory is one of the largest marble processing plants in Ethiopia. Saba Dimensional Stone Factory, in the north, produces marble, granite and limestone from Tigray region.

Table 2.5: Marble deposit in Northern Ethiopia (Tigray region) (Sentayehu, 2011)

No.	Name of Marble	Location	Estimated Deposit
1.	Naeder Marble	Naeder - Adet wereda,55km from Axum	$8.23*10^8 m^3$
2.	Dichinamo Marble	Western Tigray,30 km from Shiraro	$242*10^6 m^3$
3.	Newi Marble	Kola tembien wereda,42km NW of Abi – adi	$14.72*10^6 m^3$
4.	Adiwoyane Marble	Kola tembien wereda,13km SW of Abi – adi	$6.87*10^5 m^3$
5.	Taget Marble	Kola tembien wereda,8km SW of Abi – adi	
6.	Emnizong Marble	Medebay Zanawereda,60km South of axum	288,850 m^2
7.	Akmara Marble	Kola tembien wereda,44km NW of Abi – adi	$534*10^6 m^3$
8.	Ende – tukrir / Tekeze Marble	Western Tigray,52km SW of Shiraro and about 153km SW of Shire - Endaslassie town	$193.76*10^6 m^3$

Marble processing in Ethiopia

Historical Background

According to Ethiopian Marble industry profile, Italian investors primarily established marble processing industry called "The Ethiopian Marble Processing Enterprise" the establishment dates many years back. It was during the time of Italian occupation, a man know n as Signore Loliva Cesare, who erected the first marble processing plant in Gullelie area, under the name of "Ethio - Marble" the pioneer of the processing plant started producing Marble for the purpose of monuments, tiles and window sills. In 1961E.C the raw materials for Marble products were supplied from Asmara, Mekele and Harar quarries.

In 1950's E.C another Italian investor named Paulo - Mota erected the second plant in bole area. In 1960's E.C another Italian investor named Signore Frankety erected the third plant in nifas silk area. In 1974 E.C during public uprising in the country, the country's economic system was changed to command economy; Nationalization of private enterprise took place, at this time there are several marble processing plants in Ethiopia.

2.2.5. Marble Waste Powder

2.2.5.1. Marble Waste Powder Definition

Marble waste powder is one of the wastes produced from the marble processing plants during the cutting, shaping and polishing. During this process, about 20 – 30% of the process, marble is turned to the powder form (Arshad, Shahid, Anwar and Shakier, 2014).

2.2.6. Properties of Marble Waste Powder

2.2.6.1. Chemical Properties of Marble Waste Powder

Table 2.6: Chemical properties of Marble waste powder (Bhole, 2014).

Property	% wt.
Fe_2O_3	1.09
Na_2O	0.63
MgO	18.94
Al_2O_3	1.09
CaO	32.23
SiO_2	4.99
Loss on Ignition (LOI)	40.63

2.2.6.2. Physical properties of Marble Waste Powder

Table 2.7: Physical properties of Marble Waste Powder (Hameed and Sekar, 2013).

Property	
Bulk Density(kg/m3)	1118
Specific Gravity	2.69
Moisture content(dry) %	1.59
Moisture content(wet) %	23.35
Fineness modulus	2.04
Effective size(mm)	0.17
Coefficient of uniformity	1.58
Coefficient of gradation	1.37

2.2.7. Uses of Marble Waste Powder

Marble of extremely high purity with a bright white color is very useful. It is often mined in a way that it is crushed to a powder and then processed to remove as many impurities as possible. The resulting product is called "whiting". This powder is used as a coloring agent and filler in paint, whitewash, putty, plastic, grout, cosmetics, paper and other manufactured products (Peter, 2005).

In acidic reaction is used for acid neutralization in the chemical industry. A pharmaceutical product known as "Tums" is a small calcium carbonate pill (Medicine), sometimes made from powdered marble that is used by people who suffer from acid reflux or acid indigestion. Powdered marble is used as inert filler in other pills. The low hardness and solubility of marble allows it to be used as a calcium additive in animal feeds. Calcium additives are especially important for dairy cows and egg - producing chickens. It is also used as a low hardness abrasive for scrubbing bathroom and kitchen fixtures (Peter, 2005).

Marble waste powder as a substitute material rather than a filler in hot mix asphalt concrete production (Sevilkofteci and kockal, 2014).

2.3. Asphalt

2.3.1. Asphalt Ingredients

There are actually two basic ingredients in asphalt concrete. The first is aggregate; this is a mix of crushed stone, gravel, and sand. Aggregates make up about 95% of hot mix asphalt pavement. The other 5% is bitumen. Bitumen is the black or dark viscous material that holds the aggregates together, and is composed of polycyclic hydrocarbons (petroleum by - product) (Burdon, 2004). Bitumen is an excellent waterproofing material and is unaffected by most acids, alkalis (bases) and salts. This means that a properly constructed hot mix asphalt pavement is waterproof and resistant to many types of chemical damage (Manual series – 22, 1998).

Production of Asphalt

Asphalt can be produced in a fixed plant or even in a mobile mixing plant. It is possible to produce up to 800 tons per hour. The average production temperature of hot mix asphalt is between 150 and 190°C, which depends, however on the mixture produced (European Asphalt Pavement Association, 2015).

2.3.2. Types of Asphalt

To be able to provide the best performance to different sectors, a large variety of asphalt mixes can be offered. Due to the different requirements e.g. a road needs to fulfill (high traffic, tough weather conditions etc.) the respective mix used needs to have a sufficient stiffness and resistance to deformation in order to cope with the applied pressure from vehicle wheels on the one hand, yet on the other hand, the need to have an adequate flexural strength to resist cracking caused by the varying pressures exerted on them. Moreover, good workability during application is essential in order to ensure that they can be fully compacted to achieve optimum durability (European Asphalt Pavement Association, 2015).

2.3.2.1. Cold Mix Asphalt

Cold mix asphalt is produced without heating the aggregate. This is only possible, due to the use of a specific bitumen emulsion which breaks either during compaction or during mixing. After breaking, the emulsion coats the aggregate and over time, increases its strengths. Cold mixes are particularly recommended for lightly trafficked roads (European Asphalt Pavement Association, 2015).

2.3.2.2. Warm Mix Asphalt

A typical warm mix asphalt is produced at a temperature around 20 - 40 °C lower than an equivalent hot mix asphalt. Less energy is involved and, during the paving operations, the temperature of the mix is lower, resulting in improved working conditions for the crew and an earlier opening of the road (European Asphalt Pavement Association, 2015).

2.3.2.3. Hot Mix Asphalt

Hot mix asphalt is produced at a temperature between 150 and 190 °C, it is the highest quality among the different types. Hot mix asphalt paving material consists of a combination of aggregates that are uniformly mixed and coated with asphalt cement (bituminous binder). To dry the aggregates and obtain sufficient fluidity of the asphalt cement for proper mixing and workability, both must be heated prior to mixing - giving origin to term “ hot - mix ”.

The aggregates and bituminous binder are combined in an asphalt mixing facility, continuously or in batch - mode. These two main components are heated to proper temperature, proportioned, and mixed to produce the desired paving material. After plant mixing is complete, the hot - mix is transported to the paving site and spread with a paving machine is a partially - compacted layer to uniform, smooth surface. While the paving mixture is still hot, it is further compacted by heavy self - propelled rollers to produce a smooth, well - consolidated course of asphalt concrete (Manual series - 2, 1997).

Hot mix asphalt is used worldwide as a practical solution to water storage, flood control, erosion, and conservation problems. Pavements constructed of high - durability hot mix asphalt mixes are used increasingly for freight yards, where they stand up to heavy static loads (Randy, 2014). Such kind of asphalt has been used in this research.

2.3.2.3.1. Properties considered in Hot - Mix Asphalt

Hot mix asphalt pavements perform well placed to provide certain desirable properties. These include stability, durability, impermeability, workability, flexibility, fatigue resistance and skid resistance (Manual series - 22, 1998).

Stability

Stability of an asphalt pavement is its ability to resist shoving and rutting under traffic. A stable pavement maintains its shape and smoothness under repeated loading. An unstable pavement develops ruts, ripples (wash boarding or corrugation) and other signs of mixture shifting.

Because stability specifications for a pavement depend on the Traffic using the pavement, stability requirements can be established only after a through traffic analysis. Stability specifications should be high enough to handle traffic adequately, but not higher than traffic conditions require. A stability value that is too high produces a pavement that is too stiff and therefore less durable.

The stability of a mixture depends on internal friction and cohesion. Inter particle friction among the aggregate particles is related to aggregate characteristics such as shape and surface texture. Cohesion results from the bonding ability of the asphalt. A proper degree of both inter particle friction and cohesion in a mix prevents the aggregate particles from being moved past each other by the forces exerted by traffic. In general, more angular aggregate particles with rougher surface texture will increase the stability of the mix.

The binding force of cohesion increases with an increasing loading rate. Cohesion also increases as the viscosity of the asphalt increases, or as the pavement temperature decreases. Additionally, cohesion will increase with increasing asphalt content, up to a certain point. Past that point, increasing asphalt content creates too thick a film on the aggregate particles, resulting in loss of inter particle friction (Manual series – 22, 1998).

Table 2.8: Causes and effects of pavement Instability (Manual series – 22, 1998).

Causes	Effects
Excess asphalt in mix	Wash boarding , rutting and flushing or bleeding
Excess medium size sand mixture	Tenderness during rolling and for period after construction , difficulty in compacting
Round aggregate , little or no crushed surfaces	Rutting and channeling

Durability

The durability of an asphalt pavement is its ability to resist factors such as aging of the asphalt, disintegration of the aggregate, and stripping of the asphalt film from the aggregate. These factors result from weather, traffic, or a combination of the two.

Generally, the durability of a mixture can be enhanced by three methods:

- Designing the mix using a dense gradation of moisture - resistant aggregate
- Maximizing the asphalt film thickness on the aggregate
- Compacting the in - place mixture up to 8 percent or less air voids

Asphalt film thickness is related to asphalt content and grade of asphalt binder. Thick asphalt film do not age and harden as rapidly as thin ones do. Consequently, the asphalt retains its original characteristics longer. Also, increased film thickness effectively seals off a greater percentage of interconnected air voids in the pavement, making it difficult for water and air to penetrate. A certain percentage of air voids must retain in the pavement to allow for expansion of the asphalt in hot weather and the pressure of traffic acting on the surface.

A dense gradation of sound, tough, moisture - resistant aggregate contributes to pavement durability in three ways. It provides closer contact among aggregate particles, enhancing the impermeability of the mixture. A sound, tough aggregate resists disintegration under traffic loading. Moisture - resistant aggregate prevents the action of water and traffic from stripping off the asphalt film and leading to raveling of the pavement. Designing the mixture for maximum density and compacting the pavement up to 8 percent or less air voids also minimizes the intrusion of air and water into the pavement (Manual series – 22, 1998).

Table 2.9: Causes and effects of lack of Durability (Manual series – 22, 1998).

Causes	**Effects**
Low asphalt content	Dryness or raveling
High void content through design or lack of compaction	Early hardening of asphalt followed by cracking or disintegration
Water susceptible (hydrophilic) aggregate in mixtures	Asphalt film stripes from aggregate leaving an abraded, raveled or mushy pavement

Impermeability

Impermeability prevents the passage of air and water into or through the asphalt pavement. This characteristic is related to the voids content of the compacted mixture, and much of the discussion on voids in mix design relates to impermeability. Even though voids content is an indication of the potential for passage of air and water through a pavement, the character of these voids is more important than the number of voids. The size of the voids, whether or not they are interconnected, and the access of the voids to the surface of the pavement, all determine the degree of impermeability.

Although impermeability is important for durability of compacted paving mixtures, virtually all asphalt mixtures used in high way road construction are permeable to some degree. This is acceptable as long as it is within specified limits.

Table 2.10: Causes and effects of permeability (Manual series – 22, 1998).

Causes	Effects
Low asphalt content	Thin asphalt films will cause early aging and raveling
High void content in design mix	Water and air can easily enter pavement, causing oxidation and disintegration
Inadequate compaction	Will result in high voids in pavement, leading to water infiltration and low strength

Workability

Workability describes the ease with which a paving mixture can be placed and compacted. Mixtures with good workability are relatively easy to place and compact: those with poor workability are difficult to place and compact changing mix design parameters, aggregate source, and/or gradation can improve workability.

Harsh mixtures (mixture containing a high percentage of coarse aggregate) have a tendency to segregate during handling and also may be difficult to compact. Through the use of trial mixes in the laboratory, additional fine aggregate and perhaps asphalt can be added to a harsh mix to make it more workable. Care should be taken to ensure that the altered mix meets all other design criteria. Too high a filler content can also affect workability. It can cause the mix to become gummy, making it difficult to compact.

Workability is especially important where quite a bit of hand placement and raking (luting) around manhole covers, sharp curves, and other obstacles are required. It is important that mixtures used in such areas be highly workable.

Mixtures that can be too easily worked or shoved are referred to as tender mixes. Tender mixes are too unstable to place and compact properly. They are often caused by:

- A shortage of mineral filler
- Too much medium - size sand
- Smooth, rounded aggregate particles
- And/or too much moisture in the mix

Although not normally a major contributor to workability problem, bitumen binder does have some effect on workability. Because the temperature of the mix affects the viscosity of the asphalt, a temperature that is too low will make a mix unworkable, and a temperature that is too high may make it tender. Asphalt grade may also affect workability, as may the percentage of asphalt in the mix.

Table 2.11: Causes and effects of workability problems (Manual series – 22, 1998).

Causes	Effects
Large maximum - size particle	Rough surface, difficult to place
Excessive coarse Aggregate	Maybe hard to compact
A mix temperature that is too low	Uncoated aggregate, not durable, rough surface, hard to compact
Too much medium - size sand	Mix shoves under roller, remains tender
Low mineral filler content	Tender mix, highly permeable
High mineral filler content	Mix may be dry or gummy, hard to handle, not durable

Flexibility

Flexibility is the ability of an asphalt pavement to adjust to gradual settlements and movements in the sub grade without cracking. Since virtually all sub grades either settle (under loading) or rise (from soil expansion), flexibility is a desirable characteristic for all asphalt pavements.

An open - graded mix or one with high asphalt content is generally more flexible than a dense - graded mix or one with low asphalt content. Sometimes the need for flexibility conflicts with the need for stability, so that trade - offs have to be made in selecting the optimum asphalt content.

Fatigue resistance

Fatigue resistance is the pavements resistance to repeated bending under wheel loads (traffic). Research shows that air voids and asphalt viscosity have a significant effect on fatigue resistance. As the percentage of air voids in the pavement increases, either by design or lack of compaction, pavement fatigue resistance is drastically reduced. Likewise; a pavement containing asphalt that has aged and hardened significantly has reduced resistance to fatigue.

The thickness and strength characteristics of the pavement and the support of the sub grade also have a great deal to do with determining pavement life and preventing load - associated cracking. Thick, well - supported pavements do not bend as much under loading as thin or poorly supported pavements do. Therefore, they have longer fatigue lives.

Table 2.12: Causes and effects of poor Fatigue resistance (Manual series – 22, 1998).

Causes	Effects
Low asphalt content	Fatigue cracking
High design voids	Early aging of asphalt followed by fatigue cracking
Lack of compaction	Early aging of asphalt followed by fatigue cracking
Inadequate pavement thickness	Excessive bending followed by fatigue cracking

Skid resistance

Skid resistance is the ability of an asphalt surface to minimize skidding or slipping of vehicle tires, particularly when wet. For good skid resistance, tire tread must be able to maintain contact with the aggregate particles instead of riding on a film of water on the pavement surface (hydroplaning). Pavement skid resistance is typically measured at 65km/hr (40mi/hr) with a standard tread tire under controlled wetting of the pavement surface.

A rough pavement surface with many little peaks and valleys will have greater skid resistance than smooth surface. best skid resistance is obtained with rough - textured aggregate in a relatively open - graded mixture with an aggregate of about 9.5 mm (3/8 in) to 12.5 mm (1/2 in) maximum size. Besides having a rough surface, the aggregates must resist polishing (smoothing) under traffic. Calcareous aggregates polish more easily than siliceous aggregate. Unstable mixtures that tend to rut or bleed present serious skid resistance problems.

Table 2.13: Causes and effects of poor Skid resistance (Manual series – 22, 1998).

Causes	Effects
Excess asphalt	Bleeding, low skid resistance
Poorly textured or graded aggregate	Smooth pavement, potential for hydroplaning
Polishing aggregate in mixture	Low skid resistance

2.3.2.3.2. Mixture characteristics and behavior

When a sample paving mixture is prepared in the laboratory, it can be analyzed to determine its probable performance in a pavement structure. The analysis focuses of seven characteristics of the mixture and the influence those characteristics are likely to have on mix behavior.

These are:-

- Mix density
- Asphalt content
- Bulk Specific Gravity
- Marshal Stability and Flow
- Percent Air voids
- Percent Voids in the mineral Aggregate
- Percent Voids filled with asphalt

Mix density

The density of the compacted mix is its unit weight or the weight of a specific volume of the mix. Density is particularly important because high density of the finished pavement is essential for lasting performance.

It is calculated by multiplying the bulk specific gravity of the mix by the density of water [1000kg/m^3 (62.416 lbs. /ft^3)]. The specimen density and the maximum theoretical density, both of which are determined in the laboratory, are each used as standards to determine if the density of the finished pavement meets specification requirements (Manual series – 22, 1998).

Asphalt content

The asphalt content in the mixture is critical and must be accurately determined in the laboratory and then precisely controlled on the job. The asphalt content for a particular mix is established by using specific criteria of mix design method.

The optimum asphalt content of a mix is highly dependent on aggregate characteristics such as gradation and absorption. Aggregate gradation is directly related to optimum asphalt content. The finer the mix gradation, the larger the total surface area of the aggregate and the greater the amount of asphalt required to uniformly coats the particles. Conversely, coarser mixes have less total aggregate surface area and demand less asphalt.

Aggregate absorption is critical in determining the optimum asphalt content because enough asphalt must be added to the mix to allow for absorption and still coat the particle with an adequate film. The absorption for established aggregate sources is generally known, but requires careful testing when using new aggregate sources.

Two methods of expressing asphalt content are used in hot mix asphalt technology; total asphalt content and effective asphalt content. Total asphalt content is the amount of asphalt that must be added to the mixture to produce the desired mix qualities. Effective asphalt content is based on the volume of asphalt not absorbed by the aggregate of asphalt that effectively forms a bonding film on the aggregate surfaces.

Effective asphalt content was calculated by:

$$Pbe = Pb - \left(\frac{Pba}{100}\right) Ps \qquad (1)$$

$$Pba = 100 \left(\frac{Gse - Gsb}{Gse \times Gsb}\right) Gb \qquad (2)$$

$$Gse = \frac{Pmm - Pb}{\frac{Pmm}{Gmm} - \frac{Pb}{Gb}} \qquad (3)$$

Where:

Pba = absorbed asphalt, percent by weight of aggregate.

Pmm = Percent by weight of total loose mixture (100).

Pb = Bituminous binder, % by weight of mix

Bulk Specific Gravity

The bulk specific gravity test on the freshly compacted specimens may be performed as soon as when they have cooled to room temperature. This test is conducted according to ASTM D 2726 or D1188 / AASHTO T 166 “Bulk specific gravity of compacted bituminous mixtures using saturated surface - dry specimens”.

In the Marshal Mix design procedure, the density varies with asphalt content in such a way that it increases with increasing asphalt content in the mixture as the hot asphalt lubricants the particles allowing the compaction effort to force them closer together. The density reaches a peak and then begins to decrease because additional asphalt cement produces thicker films around the individual aggregates, and tend to push the aggregate particles further apart subsequently resulting lower density.

The bulk density of the compacted mixture can also be altered with the proportion of mineral filler. It is expected that the bulk density increases as the amount of mineral filler increases in the mixture up to some point and then decreases. This is because an increased amount of mineral fillers will increase the amount of fines in the mix and the large amount of fine particles tend to push the larger particles apart and act as lubricating ball - bearings between these larger particles which subsequently lower the bulk density.

On the other hand, using different types of mineral fillers, depending on their characteristics, may also vary the bulk density of the mixtures. This measurement is essential for an accurate density or air voids analysis.

Marshal Stability and Flow

After the bulk specific gravities have been determined, the marshal stability and flow tests are performed. It is the maximum load carried by a compacted specimen tested at 60^0C at a loading rate of 50.8mm/minute. The stability value obtained is an indication of the mass viscosity of the aggregate - asphalt cement mixture. In most cases, it is affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement at 60^0C. Hence, one of the easiest ways to increase the stability of an aggregate - asphalt mixture is to use a higher viscosity grade of asphalt cement. It is also possible to increase the stability of the mix by selecting a more crushed angular aggregate than rounded shape aggregates. Marshal stability testing aims at measuring the mix’s resistance to deformation under loads.

The flow is measured as the vertical deformation of the specimen in hundreds of inch from start of loading up to the point where the stability begins to decrease. It is obtained at the same time as the marshal stability test is conducted. Generally, high flow values indicate a plastic mix that is more prone to permanent deformation problem due to traffic loads, whereas low values may indicate a mix with higher than normal voids and insufficient asphalt for durability and could result premature cracking due to mixture brittleness during the life of the pavement. Flow testing measures the amount of deformation that occurs in the mix under loading.

Percent Air voids

Air voids are small pockets of air between the coated aggregate particles in the final compacted hot mix asphalt. A certain percentage of air void is necessary in the finished hot mix asphalt to allow for a slight amount of compaction under traffic and a slight amount of asphalt expansion due to temperature increases. The allowable percentage of air voids in laboratory specimens are between 3 percent and 5 percent for surface and base courses, depending on the specific design. The durability of an asphalt pavement is a function of air voids content. The lower the air voids, the less permeable the mixture becomes. An air voids content that is too high provides passageways through the mix for the entrance of damaging air and water. An air void content that is too low can load to flushing or bleeding.

Density and air voids content are directly related. The higher the density is, the lower the air voids in the mix will be, and vice versa. Job specifications usually require that pavement compaction achieves air void content of less than 8 percent and more than 3 percent.

The percent air void was calculated by:

$$Va = 100 \times \frac{(Gmm - Gmb)}{Gmm} \qquad (4)$$

Percent Voids in the Mineral Aggregate

The voids in the mineral aggregate, VMA, is the total available volume of void between the aggregate particles in the compacted paving mixture that includes the air voids and the effective asphalt content expressed as a percent of the total volume.

The VMA has two components: the volume of voids that is filled with asphalt, and air volume remaining after compaction for thermal expansion of the asphalt cement during hot weather. It is significantly important for the performance characteristics of a mixture. For any given mixture, the VMA must be sufficiently high enough to ensure there is space for the required asphalt cement, for its durability purpose, and air space. If the VMA is too small, there will be no space for the binder required to coat around the aggregate and this subsequently results in durability problems. On the other hand, if VMA is too large, the mixture may suffer stability problems. The available VMA will decrease as the amount of mineral fillers in the mixture increases. This can be due to both fillers can be used for filling voids or extend the asphalt binder.

The percent void in the mineral Aggregate was calculated by:

$$VMA = 100 - \frac{Gmb \times Ps}{Gsb} \qquad (5)$$

Where:

Ps = Aggregate content, % by weight of total mixture (100 – Asphalt, % by weight of mix).

Gsb = Bulk specific gravity of aggregate.

Percent Voids Filled with Asphalt

The voids filled with asphalt, VFA, is a percentage of intergranular voids space between the aggregate particles that are filled with asphalt cement. The amount of asphalt cement that fills the voids in the mixture is termed as “effective asphalt content”. It is the effective asphalt cement that provides the required asphalt film thickness around the aggregate particles, which subsequently determines the durability of the mixture.

The percent void filled with Asphalt was calculated by:

$$VFA = 100 \times \left(\frac{VMA - Va}{VMA}\right) \qquad (6)$$

Indirect tensile strength

A cylindrical test specimen is loaded on two diametrically opposite sides. This induces a tensile stress in the test specimen. The test is performed with a constant deformation speed until failure; the maximum load is recorded and is used to calculate the indirect tensile strength. Indirect tensile strength of a given specimen was determined using ASTM D 3967or ASTM 6931. The results can be used to evaluate the relative quality/strength of materials (TLTM, 2000).

The Indirect tensile strength was calculated by;

$$S_t = \frac{2000\ Pmax}{\Pi\ DH} \quad \text{or} \quad S_t = \frac{(636.62 * Pmax)}{DH} \qquad (7)$$

Where:

St = Indirect tensile strength (KPa)

Pmax = Maximum load at failure (N)

D = Diameter of specimen (mm)

H = Thickness of specimen (mm)

E - Modulus

The E - Modulus is often used for pavement design purposes. Incorrect measurements, due to poor measuring routines or sample preparation, may over or underestimate the load distribution properties of the material. This may in the worst cases lead to under dimension of the pavement structure and cause premature cracking and failure (TLTM, 2000).

The materials E – modulus was calculated by;

$$E_{mod} = 6.1 * St + 100\ (MPa) \qquad (8)$$

Where:

St = Indirect tensile strength (KPa)

2.4. Some previous studies of using marble waste as filler in asphalt mixture

Berhanu (2009) conducted Marshal Stability tests on bituminous mixes with 60/70 grade bitumen and mineral fillers such as stone dust, marble and limestone. Generally, Marshal Stability values of all mixes were improved with the addition of fillers. This attributes to the fact that lower air voids can be achieved as filler content in the mix increases. The conclusions made in this study include:

- From the low temperature tensile strength test, higher values were exhibited by mixes prepared using marble dust. This shows better performance can be achieved by using marble dust in paving mixtures when compared to others.
- The content of fillers in the mixture has greater influence in determining the optimum asphalt content and strength where, better results could be found at 5 to 7.5% filler content.
- Higher values of comprehensive strength and modulus of elasticity were achieved by mixes prepared using marble dust as compared to lime and stone dust.

- From the low temperature tensile strength test, higher values were exhibited by mixes prepared using marble dust. This shows better performance can be achieved by using marble dust in paving mixtures when compared to others.

Abrar (2011) was conducted an investigation on using marble waste powder in cement and concrete production. The research was carried out using marble waste powder and cement in different proportions. From various tests conducted, the Authors arrive at the following conclusions:

- Marble waste powder from the Ethiopian marble processing enterprise used for the study satisfies the chemical standard requirements of EN 197 – 1 (ASTM C – 150; Millier (1931)) for production of Portland limestone cement; and natural fineness of the marble waste is comparable with that of the fineness of modern cements to be used as a filler.
- Replacement of ordinary Portland cement by marble waste powder at 5% replacement range gives comparable comprehensive strength with that of 100% ordinary Portland cement. Replacement at 10%, 15% and 20% replacement ranges result comprehensive strength reduction than that of 100% ordinary Portland cement. However blended cements with 5 to 15% replacement ranges satisfy the standard of high early strength of class 42.5Mpa and blended cements at 20% replacement range satisfy the standard of high early strength of class 32.5Mpa as per the EN 197 - 1 standard (ASTM C – 150; (Millier, 1931)).
- In concrete production replacement of 5% cement by marble waste powder gives comparable comprehensive and flexural strength as of marble waste free concrete specimen; but increasing the replacement range beyond 5% results in strength reduction.
- The replacement of 5% cement by marble waste powder reduces water penetration depth in concrete specimens; but increasing the replacement range beyond 5% increases water penetration depth of concrete specimens.

Sevilkofteci and Niyaziugurkockal (2014) evaluated the effects of using marble wastes as fine aggregate in hot mix asphalt concrete production.in the study, recycling of marble waste powder for the production of hot mix asphalt concrete. The following conclusions can be drawn based on the results obtained from the study:

- It has shown that using 100% RMA as a fine aggregate has had the best Marshal Stability performance when evaluated in terms of Marshal Stability.

- It shows 100% RMA mixtures have had the best flexibility performance according to Marshal Flow values. Then 100% RMA can be used as fine aggregates in hot asphalt mixtures as binder layer.

Choudhary and Chandra (2005) conducted an investigation on Granite and Marble dusts as filler in asphalt concrete. Samples were prepared having granite and marble dust filler. The optimum binder content was then determined by Marshal Test procedure. They have also carried out Rheological tests on both mixes using granite and marble dust.

The research concluded that the addition of marble and granite dusts to asphalt concrete can produce properties comparable to the conventional asphalt concrete mixes with stone dust as filler. These fillers can be used up to 7% in asphalt concrete mixes. But it is suggested to use them in the range of 4 to 5% initially to observe their performance in field. Rheological tests conducted on filler - asphalt mastic showed the highest value of granite dust indicating high resistance to rutting of this filler. Optimum binder content of a mix reduces with increase in marble dust in the mix. This shows that this filler acts as bitumen extender also. Other results of Marshal Tests, creep tests and moisture susceptibility tests also indicate that marble dust and granite dust can be successfully utilized as a filler in bituminous construction. Their use in road construction was alleviating the problem of their disposal and environmental pollution.

Asmael (2010) evaluated the effect of mineral filler type and content on properties of asphalt concrete mixes. Based on the experiment of the study; the authors arrive the following conclusions was made:

- Fly ash has less workability and less tensile strength of asphalt concrete mixtures when compared to other asphalt concrete mixes.
- Silica fume and Portland cement have more workability and higher tensile strength in asphalt concrete mixes.
- The compaction effort required to achieve density increases as the concentration of filler in asphalt concrete mixtures is increased.
- The incorporation of Fly ash filler in the mixture will always cause a significant reduction in mixtures mechanical properties.

Abed and Sadoon (2005) evaluated the use of Sulaimania Marble waste to improve the properties of hot mix asphalt concrete. Based on the results of the study made the following conclusions:

- The use of Sulaimania Marble waste as a filler in hot mix asphalt concrete will increase Marshal Stability of the mix. It also increases the air voids and flow, and decreases the density of mix, this effect almost matching with the specifications. Adding Sulaimania Marble waste to the mix reflects a good effect on the cohesion of the mix due to high value of indirect tensile strength while showing high effectiveness to change in temperature with high value of temperature susceptibility.
- The abundant effect of Sulaimania Marble waste of indirect retained strength value refers to its importance to reduce the moisture attack.

Zemichael (2007) evaluated the effect of different types of filler materials on characteristics of hot mix asphalt concrete. The authors have carried out marshal stability, moisture susceptibility of mixtures and Dynamic complex modulus of hot mix asphalt tests. The conclusions made in this study include:

- The bulk density increases up to some point and then decreases with increasing filler content in the mixture using crushed stone and volcanic - cinder. While for mixtures with limestone filler, the bulk density keeps increasing with the filler content.
- Stability value of mixes prepared with crushed stone and limestone were found to be increasing up to maximum and then decreasing with the increase in the amount of filler content starting from 4%. Whereas, the stability value of mixes containing volcanic - cinder keeps increasing with the filler content.
- Higher stability values were obtained from mixtures containing volcanic - cinder for all filler contents. Mixes prepared with crushed stone provide higher stability values than the mixes containing limestone for all fillers content except 6% and 8%.
- Voids filled with asphalt (VFA) values of mixtures using 2% of all types of mineral fillers and 4% of crushed stone were found to be higher than the maximum value of Marshal criteria.
- The effective asphalt content in the mix provides the required film thickness around the aggregate particles. It is the available film thickness that determines flexibility and durability of mixtures. Mixes made with volcanic - cinder have lower effective asphalt content as compared to mixes containing limestone and crushed stone fillers. Thus, mixtures containing volcanic - cinder have lower film thickness around aggregate particles than mixes containing either limestone or crushed stone fillers and may be less durable.

Debashish, Mahabir Panda and Giri (2014) conducted a study influence of Fly - ash as a filler in bituminous concrete mixes. From the results of Marshal Tests and other performance tests conducted the stability of Fly ash as filler in bituminous concrete mixes the authors arrive at the following conclusions:

- The optimum bitumen content requirement in case of cement and stone dust are same while for Fly ash, the same is slightly higher.
- At a particular temperature, the indirect tensile strength of bituminous concrete mixes with cement as filler have the highest value followed by some dust and Fly ash.
- It is observed that the value of retained stability for mixes prepared with cement as filler offers highest retained stability value followed by stone dust and Fly ash filler. However, the variations are so small to be considered significant and all the mixes satisfy the minimum retained stability value requirement. i.e.75%. It means all the mixes including that with Fly ash as filler have very good resistance to moisture induced damages.
- In general, Fly ash can effectively be used as filler in paving mixes in place of most commonly used fillers such as Ordinary Portland cement and Stone dust. The former leads to high cost and the latter may be costly at certain places where coarse aggregates are scarce. Moreover, use of Fly ash in paving mixes may give a solution to the Fly ash utilization and disposal problems and also give a means to make the environment safe and clean.

Huseyin, Gurer, Sedat Cetin and Elmaci (2016) conducted an Investigation of marble (granite) sludge as filler in bituminous hot mixtures. The conclusions made in this study:

- Optimum bitumen content levels were calculated for each of the different filler percentages. According to this study, optimum bitumen content percentages were calculated as 5.11%, 4.76%, 4.10%, 4.04% and 3.83% when filler content percentages were set at 0%, 2%, 4%, 6% and 8%, respectively. It was seen that the optimum bitumen content level fell within the economical limits for all of the bituminous hot mixture specimens. Because of the active filler properties of the marble (granite) sludge, increasing percentages of filler corresponded with decreasing optimum bitumen content levels.
- Filler materials fill the micro voids in the bituminous hot mixture, so the density increases. As a result, it was determined that if marble (granite) sludge filler was used as 6.4% of the mix, a denser bituminous hot mixture specimen will be obtained. For this reason, it was expected that specimens with 6% filler would have maximum stability value was in fact

shown in specimens with 8% filler. An important cause of this could be that adding 8% filler to the mix filled the micro voids better than other levels of filler content.

- The optimum bitumen content was calculated at 7.3% for filler containing recycled marble (granite) sludge. This indicates that the performance of bituminous hot mixture used in wearing courses could be better if the filler were used at the 7.3% level.
- Generally, different characteristics of bituminous hot mixtures were observed when the fillers in the mixture were varied by type and content. This indicates that, mineral fillers are significant ingredients affecting mixture properties.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

This study involved investigating the Marshal properties of bituminous mixtures prepared in the laboratory using different types of mineral fillers (all passes No. 200 sieves); namely crushed dust, marble waste powder and cement.

This study involved collecting of materials for the preparation of bituminous mixtures. The materials used in the mixture include: coarse and fine aggregates, different types of mineral fillers, and asphalt binder.

The crushed stone coarse and fine aggregates were obtained from Maytsebri – Shire road upgrading project crusher site which is located at the entrance of Indabaguna town and marble waste powder (slurry form) from Saba Dimensional Stone Processing Factory pit which is located at Adwa to be used as a filler material. The asphalt binder was obtained from Maystebri – Shire road upgrading project stock.

These ingredient materials were subjected to various laboratory tests in order to determine their physical properties whether they can meet the project specification limits. These quality assurance tests were conducted on the aggregate based on sieve analysis, Los Angeles abrasion, soundness, flakiness, aggregate crushing value, asphalt affinity, specific gravity and water absorption tests. The tests such as flash point, ductility, penetration, specific gravity and softening point were carried out on the asphalt binder. The obtained test results are indicated in Table - 3.2, 3.4 & 3.6 and comparison with Maytsebri – Shire road upgrading project specifications are indicated in Table - 3.1, 3.3 and 3.5.

Specimens were then prepared using each type of the mineral fillers (crushed dust, cement and marble waste powder) in different proportion by weight of aggregates 2%, 2.5%, 3%, and 3.5% with different; amount of bituminous material. In accordance with the Marshal Mix design procedure and criteria, different mixture properties were obtained.

Finally, mixtures were prepared using marble waste powder at their respective optimum asphalt binder content to investigate the performance of hot asphalt mixture.

3.2. Description of the study area

Maytsebri - Shire road upgrading project which is the second contract of Zarima - Adiarkay - Shire Road Upgrading Project is approximately 68.285km and located in the northern part of Ethiopian in Tigray region. The road is an integral part of the 290km along Gonder - Shire road upgrading project and serves the traffic from Gonder and other region of Tigray. The Maytsebri - Shire road upgrading project starts about 205km from Gonder at Maytsebri town and ends 7km from Shire town. The detailed engineering design, Tender document preparation, and supervision for the road have been under taken by Sheladia in association with Hitcon Consulting Engineer and the construction have been under taken by Ethiopian Road construction corporation.

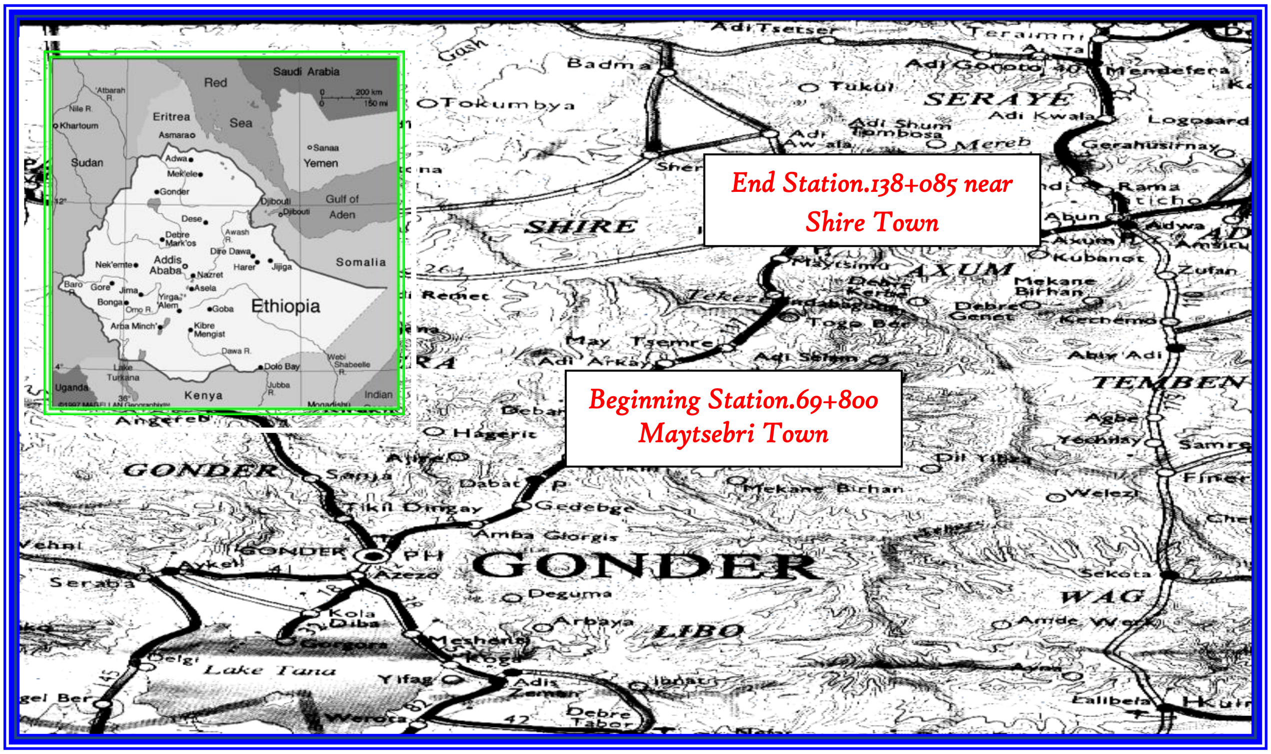

Fig 3.1: Maytsebri – Shire road upgrading project site location map

3.2.1. Topography of the study area

The Maytsebri – Shire road upgrading project road can be divided into two topographical sub sections.

i) From Imbamadri to Adigebru town

The road section is 23.6km, are mainly mountainous and Escarpment terrain. It is also difficult to construct a detour since it rotates around the foot of hills.

ii) From Maytsebri to Imbamadri and From Adigebru to Shire town

The road section is 44.68km, are mainly flat / rolling terrain.

Fig 3.2 : Topography of Maytsebri - Shire road upgrading project

3.3. Materials used in studying the performance of hot mix asphalt

3.3.1. Aggregate

The mineral Aggregates used in the research were obtained from Maytsebri - Shire road upgrading project crusher site located at the entrance of Indabaguna town, with the following characteristics, were used as fine and coarse aggregate respectively.

3.3.1.1. Aggregate quality

Aggregate is the major components in hot mix asphalt and the quality and physical properties of this material has a large influence on asphalt concrete performance. Typically the qualities required of aggregates were described in terms of shape, hardness, durability, cleanliness, soundness, water absorption, bitumen affinity and porosity.

The aggregate that has been used is crushed and unweathered rock from an approved quarry. As a result, the aggregate used for making the specimen has the following characteristics.

- Clean and free of clay and organic material.
- Angular and not excessively flaky, to provide good mechanical interlock.
- Strong enough to resist crushing during mixing and laying as well as in service.
- Resistance to abrasion and polishing when exposed to traffic.
- Non absorptive.

Table 3.1: Quality requirements of asphalt concrete aggregates ERA contract specification

Property	Test	Property
Particle shape	Flakiness index for course aggregate (%)	< 25
Strength	Aggregate crushing value, ACV (%)	< 21
	10% fineness value (dry) KN	> 210
	Wet dry ratio	> 75
	Los Angeles Abrasion, LAA (%)	< 30
Abrasion	Aggregate Abrasion Value	< 14
Soundness	Sodium sulphate soundness(SSS) coarse aggregate	< 10
	Sodium sulphate soundness(SSS) fine aggregate	< 14
Water absorption	Water absorption for coarse aggregate, %	< 1
	Water absorption for fine aggregate, %	< 1.5

Table 3.2: Laboratory quality test result for coarse and fine aggregates

Test Type	Filler	Fine Aggregate	Coarse Aggregate
Specific gravity (SSD)	2.65	2.78	2.88
Water absorption (%)	-	1.01	0.68
Los Angeles Abrasion, LAA (%)	-	-	17
Flakiness index (%)	-	-	18
10% Fineness Value (wet) KN	-	-	240
10% Fineness Value (Dry) KN	-	-	300
Aggregate Crushing Value, ACV (%)	-	-	20
Linear Shrinkage Filler Material (%)	1.18	-	-
Loose on Heating (%)	4.85	-	-
Soundness(by sodium sulphate) %	-	-	2.15

3.3.1.2. Gradation of Coarse and fine Aggregate

Aggregate grain size distribution or gradation is one of the properties of aggregates which influence the quality of hot mix asphalt. The coarse and fine aggregate particles were separated into different sieve size and proportioned to obtain the desired gradation for bituminous mixtures of ASTM 3515. Therefore, coarse aggregate [retained on 2.36mm (NO.8) sieve], fine aggregate [passing 2.36 mm (NO.8) sieve] and mineral filler [Passing 75μm (NO.200) sieve] with gradation satisfying the grading requirement of Maystebri - Shire road upgrading project contract specification.

Table 3.3: Grading limits for combined aggregate for asphalt concrete ERA contract specification

Type	Continuously – graded
Grading	Limits for nominal size of aggregate 20mm
Sieve size(mm)	Fraction passing by mass (%)
25.0	100
19.0	85 – 100
12.5	71 – 84
9.5	62 – 76
6.3	55 – 75
4.75	42 – 60
2.36	30 – 48
1.18	22 – 38
0.600	16 – 28
0.300	12 – 20
0.150	8 – 15
0.075	4 – 10

Table 3.4: Gradation of coarse and fine aggregate used for the test

Test Sieve Size (mm)	Weight Retained (gm)	Percent Retained	Percent pass	Combined asphalt aggregate specification limit	
				Lower limit	Upper limit
25.0	0	0	100	100	100
19.0	49.30	4.11	95.89	85	100
12.5	212.3	17.69	78.20	71	84
9.5	140.4	11.70	66.50	62	76
6.3	101.1	8.43	58.08	55	75
4.75	53.10	4.43	53.65	42	60
2.36	260.8	21.73	31.92	30	48
1.18	102.0	8.50	23.42	22	38
0.600	88.80	7.40	16.02	16	28
0.300	63.90	5.33	10.69	12	20
0.150	31.00	2.58	8.11	8	15
0.075	32.30	2.69	5.42	4	10
Pan	65.00	5.42	0.00		
Total	1200				

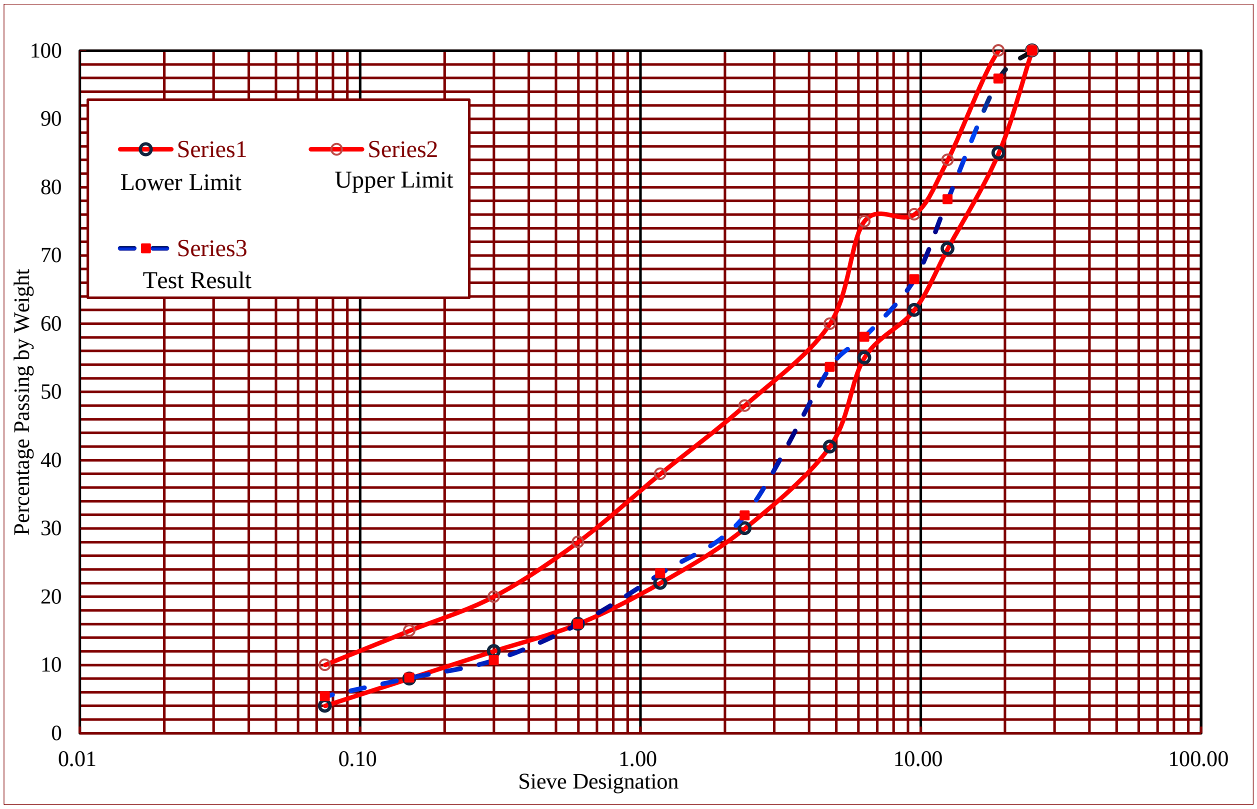

Fig 3.3: Gradation curves of coarse and fine aggregate used for the test

3.3.2. Crushed dust

Crusher dust also known as stone dust is the most commonly used filler in bituminous construction in Ethiopia, crushed dust the material passing No.200 (75-µm) (0.075mm) sieve. Their physical properties, which are believed to be major suspects of affecting the bituminous mixture property. The crushed dust used for the test was also taken from Maytsebri – Shire road upgrading project stock (crusher site).

3.3.3. Marble waste powder

Commercially called marble waste powder but geologically limestone mixed marble waste powder, a by - product of Marble Processing Factory, which is an external mineral filler taken from Saba Dimensional Stone Factory.

3.3.4. Bituminous Binder

Bituminous binder of grade 60/70 penetration was used in the preparation of mixtures since it is widely used and suitable for hot temperature area like Ethiopia. According to Manual Series – 2 (1997), the annual air temperature greater or equal to 24^0C the asphalt grade is 60/70 pen. This bituminous binder was used in the preparation of mixtures since the annual air temperature of Maytsebri – Shire road upgrading project area is greater than 24^0C. The bituminous binder used for the test was also taken from Maytsebri – Shire road upgrading project stock. The summary of test results obtained is as shown in Table 3.6.

Table 3.5: ERA contract specification of bituminous binder

Test type	Test Method (ASTM)	Specification limit
Based on original bitumen penetration at 25 ^{O} C	D5	60 – 70
Softening point(^{O}C)	D36	46 – 56
Flash point (^{O}C)	D92	> 232
Solubility in Trichloroethylene (%)	D2024	> 99
TFOT heating for 5 hr at 163 ^{O}C	D1754	
a. Loss by mass (%)		< 0.5
b. Penetration (% of original)	D5	> 54
c. Ductility at 25 ^{O}C	D113	> 50

Table 3.6: Laboratory test result of bituminous binder

No.	Test Type	Test Method	Test Results
1.	Flash Point ^{0}C	AASHTO T 48	300
2.	Ductility (cm)at 25 ^{0}C	AASHTO T 51	148
3.	Penetration at 25 ^{0}C	AASHTO T 49	66
4.	Specific gravity 25 ^{0}C	AASHTO T 228	1.03
5.	Softening Point ^{0}C	AASHTO T 53	54
6.	Thin Film Oven test % loss	AASHTO T 179	0.026
7.	Solubility in Trichloroethylene %	AASHTO T 44	99.38
8.	Ductility of Residue (cm) at 25 ^{0}C	AASHTO T 51	134
9.	Penetration of Residue at 25 ^{0}C	AASHTO T 49	58

3.3.5. Cement

For studying the effects of marble waste powder on the properties of hot mix asphalt, cement is also included in the study to compare the results. Mossobo PPC cement was used for the experiment, which was manufactured according to Ethiopian standards ES – 1177 – 1 – 2005 and European standards EN – 197 – 1 – 2000.

3.4. Experimental program

The main objectives of the experimental program are to study the effects of using marble waste powder as a filler on the performance of hot mix asphalt concrete, effects of marble waste powder by increasing the amount of marble content from ERA standard (2%), Pavement design manual (2001), and effects of asphalt binder by using different ratio, in reference to Maytsebri – Shire road upgrading project Marshal mix design of optimum bitumen content, which is 4.82% $\pm$ 0.3. To achieve these objectives, two experiments were designed.

The first experiment (experiment one) was done to prepare hot mix asphalt concrete ingredients. This experiment is an input of the next experiment.

Following experiment one, another experiment (experiment two) was performed to determine the effect of marble waste powder on hot mix asphalt performance.

3.4.1. Experiment One

Experiment one, which consists of preparation of coarse and fine aggregate, determination of physical parameters of coarse and fine aggregates, preparation of crushed dust, preparation of marble waste powder and preparation of bituminous binder was designed to determine the effects of marble waste powder on hot mix asphalt performance.

3.4.1.1. Preparation of coarse and fine aggregate

Aggregate makes up 90 - 95 percent by weight and 75 - 85 percent by volume of most hot mix asphalt concrete. Because it provides most of the load - bearing characteristics, pavement performance is heavily influenced by the choice of a proper aggregate for a particular job (Manual series – 22, 1998). Aggregate used for the experiment was taken from Maytsebri – Shire road upgrading project crusher site.

3.4.1.1.1. Determination of physical parameters of coarse and fine aggregate

Different physical parameters of aggregates are required to be within a certain limit by different standards so that the hot mix asphalt concrete from that aggregate will give the intended performance. Some physical parameters are also important as an input in hot mix asphalt concrete. Therefore, the following properties of aggregates were tested and determined.

1. Gradation of coarse and fine aggregates: - by sieving with procedures as indicated in construction material laboratory manual (Abebe Dinku, 2002). From this test the gradation of

both coarse and fine aggregates were found to be within Maytsebri – Shire road upgrading project specification limit, from this test, No.50 (300µm) was found 10.69% which is under the limit recommended by the ERA contract specification, because the Maytsebri – Shire road upgrading project crusher type is cone crusher type, the jaw cannot minimize 19.0 mm. The test results of the gradation of the aggregate used for the test (trial mix) are shown in Table 3.4.

2. Quality of coarse and fine aggregates: - Aggregates make up to 90 - 95 percent by weight of hot mix asphalt. This makes the quality of the aggregate a critical factor in pavement performance (Manual series – 22, 1998). The quality of coarse and fine aggregate was determined by methods and procedures indicated in construction materials laboratory manual (Abebe Dinku, 2002). As they are inputs of hot mix asphalt trial mixes, the quality of the aggregate (coarse and fine) is tested by CONSTRUCTION DESIGN SHARE CO. The test results of the quality of the aggregate are shown in Table 3.2.

3.4.1.2. Preparation of Crushed dust

Crushed dust is a filler material finer than 0.075mm to obtain by sieving with procedures as indicated in construction material laboratory manual (Abebe Dinku, 2002). The crushed dust is prepared from the asphalt concrete aggregate from the project crusher site.

3.4.1.3. Preparation of Marble waste powder

Marble waste powder is external mineral filler; the marble waste originally was discharged from Saba Dimensional Stone Factory in slurry form and was very wet during collection. Drying the slurry (mixtures of marble waste powder with water) results in the formation of marble powder

The interest of the research was to use the marble waste powder with its original (natural) fineness. However, as the powder comes out in the slurry form from the factory, dry and turns to larger conglomerate grain form than powder form; this required a certain manual grinding to get its original (natural) fineness. Therefore, the dried conglomerate grain was ground manually by local traditional stone mill.

3.4.1.4. Preparation of Bituminous binder

The quality of bituminous binder used for the test is tested by CONSTRUCTION DESIGN SHARE company laboratory. The laboratory test results of the bituminous binder are shown in Table 3.6.

3.4.2. Experiment Two

Experiment Two, which consists of six different Trial mix were prepared with different ratio of crushed dust, marble waste powder, bituminous binder and cement. Preparation and tests of hot mix asphalt concrete were designed to determine the effects of marble waste powder on hot mix asphalt performance.

Mix design of hot mix asphalt (HMA) can be defined as the process to determine the combination of asphalt cement (bituminous binder) and aggregate that will give long lasting performance as part of the pavement structure.

According to Maytsebri – Shire Road Upgrading Project laboratory, Mix design is approved by the Consulting Engineers. The following proportion of material used for the preparation of Trial mixes.

1. Trial Mix proportion of aggregate

Amount of total aggregate used for one specimen weighing about 1200gm. One batch of asphalt concrete contains 1200 kg of aggregate in project asphalt plant. The proportion of the materials used for test as per the project mix design as shown in Table 3.7.

Table 3.7: Proportion of aggregates of hot mix asphalt project mix design

NO.		**Asphalt aggregate classification**					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Mineral Filler
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	4	2
4.	By weight of Aggregate Mixture,gm	120	312	144	552	48	24

2. Trial mix proportion of bituminous binder

The project mix design of bituminous binder content is 4.82% $\pm$ (0.3).

3.4.2.1. Trial Mix - 1 preparation

To study the effects of marble waste powder on Trial Mix - 1, four groups of hot mix asphalt specimens were prepared.

The first group was prepared by marble waste powder 2% and bituminous binder 4.82% to study the effects on performance of hot mix asphalt.

Table 3.8: Proportion of materials for hot mix asphalt specimens of Trial Mix - 1 group one

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	4	2
4.	By weight of Aggregate Mixture,gm	120	312	144	552	48	24
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.82			57.84		

The second group was prepared by marble waste powder 2.5% and bituminous binder 4.82% to study the effects on performance of hot mix asphalt.

Table 3.9: Proportion of materials for hot mix asphalt specimens of Trial Mix - 1 group two

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	3.5	2.5
4.	By weight of Aggregate Mixture,gm	120	312	144	552	42	30
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.82			57.84		

The third group was prepared by marble waste powder 3% and bituminous binder 4.82% to study the effects on performance of hot mix asphalt.

Table 3.10: Proportion of materials for hot mix asphalt specimens of Trial Mix - 1 group three

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	3	3
4.	By weight of Aggregate Mixture,gm	120	312	144	552	36	36
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.82			57.84		

The fourth group was prepared by marble waste powder 3.5% and bituminous binder 4.82% to study the effects on performance of hot mix asphalt.

Table 3.11: Proportion of materials for hot mix asphalt specimens of Trial Mix - 1 group four

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	2.5	3.5
4.	By weight of Aggregate Mixture,gm	120	312	144	552	30	42
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.82			57.84		

For each group mix, four test specimens were prepared. Three specimens with compaction mold (102mm (4in) diameter x 75mm (3in) height) were prepared for bulk specific gravity determination, to determine voids content and measurement of stability and flow. The other one which is uncompacted mix sample for maximum specific gravity (zero voids) determination.

3.4.2.1.1. Hot mix asphalt preparation

Each weighing aggregate sample Bin I - Bin IV was blended for each specimen separately according to the mix formula. Aggregate are first dried to constant weight at 110 $\pm$ 5^{o}C. The aggregates are then heated to a temperature of 160^{o}C before mixing with bituminous binder and mineral filler. Bituminous binder was heated up to 145^{o}C prior mixing. Pre - heated bituminous binder was avoided. Excess heated bituminous binder was disposed of to avoid variability in the asphalt properties.

After the dry mix, the required amount of crushed dust, marble waste powder and heated asphalt binder were then added to the heated aggregate and mixed thoroughly for at least 45 seconds as quickly as possible to yield a mixture having a uniform distribution of bituminous binder.

After the mix is done, thoroughly clean the standard Marshal molds were heated in an oven to a temperature between 95^{o}C and160^{o}C. Place a piece of filter paper, cut to size, in the bottom of the mold before the mixture is placed in the mold. The fresh hot - mix asphalt concrete is placed and pressed in preheated mold with a heated spatula or trowel 15 times around the perimeter and

10 times over the interior. Smooth the surface slightly too rounded shape. Place a piece of filter paper on the top of the mix then place the mold assembly on the compaction pedestal in the mold holder. Apply 75 blows (as specified according to the heavy traffic design category) with the compaction hammer using a free fall of 457mm (18in). Remove the base plate and collar, reverse and reassemble the mold. Apply the same number of compaction blows to the face of the reversed specimen. After compaction, remove the base plate, filter paper and the specimen from the mold, then placed on a smooth level surface until ready for testing. Normally, the specimens were then left to cool at room temperature for 18 - 24 hours.

Finally, the last mix or uncompacted mix of fresh hot mix asphalt spread on a large pan by using spatula then left to cool at room temperature for 18 - 24 hours.

3.4.2.1.2. Determination of Maximum specific gravity of Trial mix - 1

Quartering method is used and the uncompacted mix sample divided into four parts and takes different Direction, AD or BC. Use the first specimen (quarters AD), weigh the mass of dry sample in air, measure the temperature of water (distilled water) (25^oC), fill the distilled water in Pecnometer jar and weigh the mass of the pecnometer jar with water, then place the weighted sample in the distilled water containing pecnometer jar. Shake the sample for 15 minutes. After 15 minutes, fill pecnometer jar that has sample with distilled water in the open space and then weigh. Apply the same procedures of the other sample (quarters BC).

3.4.2.1.3. Determination of Bulk specific gravity of Trial mix - 1

Using the three compacted specimens, first measure the thickness of the specimens, then weigh the specimens mass in air, mass in water (immersed in water) and mass of surface - dry in air (saturated).

3.4.2.1.4. Measurement of Stability and Flow of Trial mix - 1

After the bulk specific gravity is determined, the Marshal Stability and Flow tests were performed. Each cylindrical specimen was placed in water bath at 60^OC for 30 minutes before testing; the lower testing head and the upper testing head are heated in a water bath in a range of temperature between 40^OC and 60^OC. After that the specimen is removed from the water bath, damp dried and quickly place the specimen in the marshal apparatus of the lower testing head and center then fit upper testing head into position, apply testing load on the specimen. Then compressed on the lateral surface at constant rate of 2 inch/min.(50.8mm/min.) Until the maximum load (failure) is reached. The maximum load resistance and the corresponding flow value are recorded. Three specimens for each combination were prepared and the average results were reported.

3.4.2.2. Trial Mix - 2 preparation

To study the effects of marble waste powder on Trial Mix - 2, four groups of hot mix asphalt specimens were prepared.

The first group was prepared by marble waste powder 2% and bituminous binder 4.97% to study the effects on performance of hot mix asphalt.

Table 3.12: Proportion of materials for hot mix asphalt specimens of Trial Mix - 2 group one

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	4	2
4.	By weight of Aggregate Mixture,gm	120	312	144	552	48	24
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.97			59.64		

The second group was prepared by marble waste powder 2.5% and bituminous binder 4.97% to study the effects on performance of hot mix asphalt.

Table 3.13: Proportion of materials for hot mix asphalt specimens of Trial Mix – 2 group two

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	3.5	2.5
4.	By weight of Aggregate Mixture,gm	120	312	144	552	42	30
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.97			59.64		

The third group was prepared by marble waste powder 3% and bituminous binder 4.97% to study the effects on performance of hot mix asphalt.

Table 3.14: Proportion of materials for hot mix asphalt specimens of Trial Mix – 2 group three

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	3	3
4.	By weight of Aggregate Mixture,gm	120	312	144	552	36	36
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.97			59.64		

The fourth group was prepared by marble waste powder 3.5% and bituminous binder 4.97% to study the effects on performance of hot mix asphalt.

Table 3.15: Proportion of materials for hot mix asphalt specimens of Trial Mix - 2 group four

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	2.5	3.5
4.	By weight of Aggregate Mixture,gm	120	312	144	552	30	42
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.97			59.64		

Procedure of hot mix asphalt preparation, determination of maximum specific gravity, determination of bulk specific gravity and measurement of stability & flow and voids content determination have the same steps as trial mix - 1.

3.4.2.3. Trial Mix - 3 preparation

To study the effects of marble waste powder on Trial Mix - 3, four groups of hot mix asphalt specimens were prepared.

The first group was prepared by marble waste powder 2% and bituminous binder 5.12% to study the effects on performance of hot mix asphalt.

Table 3.16: Proportion of materials for hot mix asphalt specimens of Trial Mix - 3 group one

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	4	2
4.	By weight of Aggregate Mixture,gm	120	312	144	552	48	24
		By weight of Mixture, %		By weight of Mixture, gm			
1.	Bituminous binder (60/70)	5.12		61.44			

The second group was prepared by marble waste powder 2.5% and bituminous binder 5.12% to study the effects on performance of hot mix asphalt.

Table 3.17: Proportion of materials for hot mix asphalt specimens of Trial Mix - 3 group two

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	3.5	2.5
4.	By weight of Aggregate Mixture,gm	120	312	144	552	42	30
		By weight of Mixture, %		By weight of Mixture, gm			
1.	Bituminous binder (60/70)	5.12		61.44			

The third group was prepared by marble waste powder 3% and bituminous binder 5.12% to study the effects on performance of hot mix asphalt.

Table 3.18: Proportion of materials for hot mix asphalt specimens of Trial Mix - 3 group three

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	3	3
4.	By weight of Aggregate Mixture,gm	120	312	144	552	36	36
		By weight of Mixture, %		By weight of Mixture, gm			
1.	Bituminous binder (60/70)	5.12		61.44			

The fourth group was prepared by marble waste powder 3.5% and bituminous binder 5.12% to study the effects on performance of hot mix asphalt.

Table 3.19: Proportion of materials for hot mix asphalt specimens of Trial Mix - 3 group four

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	2.5	3.5
4.	By weight of Aggregate Mixture,gm	120	312	144	552	30	42
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	5.12			61.44		

Procedure of hot mix asphalt preparation, determination of maximum specific gravity, determination of bulk specific gravity and measurement of stability & flow and voids content determination have the same steps as the above two trial mix.

3.4.2.4. Trial Mix - 4 preparation

To study the effects of cement on Trial Mix - 4, one group of hot mix asphalt specimen was prepared.

The group was prepared by cement 2% and bituminous binder 4.82% to study the effects on performance of hot mix asphalt.

Table 3.20: Proportion of materials for hot mix asphalt specimens of Trial Mix - 4 group one

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Cement
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	4	2
4.	By weight of Aggregate Mixture,gm	120	312	144	552	48	24
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.82			57.84		

For the group mix, four test specimens were prepared. Three specimens with compaction mold (102mm (4in) diameter x 75mm (3in) height) were prepared for bulk specific gravity determination, measurement of stability and flow and to determine voids content. The other one which is uncompacted mix sample for maximum specific gravity (zero voids) determination.

Procedure of hot mix asphalt preparation, determination of maximum specific gravity, determination of bulk specific gravity and measurement of stability & flow and voids content determination have the same steps as the above three trial mix.

3.4.2.5. Trial Mix - 5 preparation

To study the effects of replacing parts of crushed dust and mineral filler totally by cement on Trial Mix - 5, one group of hot mix asphalt specimen was prepared.

The group was prepared by 6% of cement (all the filler amount of the project specification covered by cement) and bituminous binder 4.82% to study the effects on performance of hot mix asphalt.

Table 3.21: Proportion of materials for hot mix asphalt specimens of Trial Mix - 5 group one

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Cement
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	-	6
4.	By weight of Aggregate Mixture, gm	120	312	144	552	-	72
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.82			57.84		

For the group mix, four test specimens were prepared. Three specimens with compaction mold (102mm (4in) diameter x 75mm (3in) height) were prepared for bulk specific gravity determination, measurement of stability and flow and to determine voids content. The other one which is uncompacted mix sample for maximum specific gravity (zero voids) determination.

Procedure of hot mix asphalt preparation, determination of maximum specific gravity, determination of bulk specific gravity and measurement of stability & flow and voids content determination have the same steps as the above four trial mix.

3.4.2.6. Trial Mix - 6 preparation

To study the effects of replacing parts of crushed dust totally by marble waste powder on Trial Mix - 6, one group of hot mix asphalt specimen was prepared.

The group was prepared by 6% of marble waste powder (all the filler amount of the Maytsebri – Shire road upgrading project specification covered by marble waste powder) and bituminous binder 4.82% to study the effects on performance of hot mix asphalt.

Table 3.22: Proportion of materials for hot mix asphalt specimens of Trial Mix - 6 group one

NO.		Asphalt aggregate classification					
1.	Hot egat Bin Number	Bin I	Bin II	Bin III	Bin IV	Crushed Dust	Marble Powder
2.	Size of Aggregate, mm	25-19	19-9.5	9.5-4.75	4.75	Mineral Filler	
3.	By weight of Aggregate Mixture, %	10	26	12	46	-	6
4.	By weight of Aggregate Mixture, gm	120	312	144	552	-	72
		By weight of Mixture, %			By weight of Mixture, gm		
1.	Bituminous binder (60/70)	4.82			57.84		

For the group mix, four test specimens were prepared. Three specimens with compaction mold (102mm (4in) diameter x 75mm (3in) height) were prepared for bulk specific gravity determination, measurement of stability and flow and to determine voids content. The other one which is uncompacted mix sample for maximum specific gravity (zero voids) determination.

Procedure of hot mix asphalt preparation, determination of maximum specific gravity, determination of bulk specific gravity and measurement of stability & flow and voids content determination have the same steps as the above five trial mix.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Introduction

In this section, the test results on the performance of the six hot mix asphalt trial mixes made with different ratios of crushed dust, marble waste powder, cement and bituminous binder, are presented, analyzed and discussed.

4.1.1. Test results and Discussions on Trial mix - 1

In this part, the test results on the performance of the four groups of hot mix asphalt made with different amount of crushed dust and marble waste powder are presented, analyzed and discussed.

4.1.1.1. Test results and Discussions on Trial mix - 1 group one

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va) , voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA)), Stability and flow and effective asphalt content of trial mix - 1 group one.

4.1.1.1.1. Bulk specific gravity of Trial mix - 1 group one

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.1: Test results of bulk specific gravity of Trial mix - 1 group one

	Specimen Identification	1	2	3
1.	Mass in air, gm	1242.7	1232.8	1247.8
2.	Mass in water, gm	753.1	745.2	758.3
3.	Mass of surface - dry in air, gm	1243.3	1233.1	1248
4.	Volume of specimen,cm^3	490.2	487.9	489.7
5.	Bulk specific gravity , actual	2.535	2.527	2.548
	Bulk specific gravity, actual, Average (Gmb)	**2.537**		

4.1.1.1.2. Maximum specific gravity of Trial mix - 1 group one

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.2: Test results of maximum specific gravity of Trial mix - 1 group one

T 23^{O}C

	Specimen Identification	1	2
1.	Mass of dry sample in air, gm	587.5	654.4
2.	Mass of flask filled with water at 25 ^{O}C, gm	1590.7	1590.7
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	1959.3	1998.9
4.	Maximum specific gravity	2.684	2.658
	Maximum specific gravity mean value (Gmm)	**2.671**	

4.1.1.1.3. Air voids analysis of Trial mix - 1 group one

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \frac{(2.671 - 2.537)}{2.671} = \mathbf{5.03}$$

4.1.1.1.4. Voids in the mineral aggregate analysis of Trial mix - 1 group one

The voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \frac{(2.537 \text{ X } 95.18)}{2.827} = \mathbf{14.6}$$

4.1.1.1.5. Voids filled with asphalt (VFA) analysis of Trial mix - 1 group one

The voids filled with asphalt (VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \frac{(14.6 - 5.03)}{14.6} = \mathbf{65.6}$$

4.1.1.1.6. Test results of Stability and Flow of Trial mix - 1 group one

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y = 0.002X^2 + 1.262X - 0.069 \text{ x correlation ratio.}$$

Table 4.3: Test results of Stability and Flow of Trial mix - 1 group one

	Specimen Identification	1	2	3
1.	Thickness of specimen, mm	61.0	60.0	59.0
2.	Correlation ratio	1.09	1.09	1.09
3.	Stability, Measured, KN	8.28	8.07	8.49
4.	Stability, corrected, KN	11.46	11.17	11.76
5.	Stability, corrected Average, KN	11.46		
6.	Flow, mm	2.33	2.47	1.63
7.	Flow, Average, mm	2.14		

4.1.1.1.7. Effective asphalt content of Trial mix - 1 group one

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content

$$= 4.82 - \left(\frac{0.983}{100}\right) \times 95.18 \qquad = \qquad \mathbf{3.88}$$

Table 4.4: Comparison of Trial mix - 1 group one test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 1 group one
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.82
2.	Bulk specific gravity	-	2.537
3.	Maximum specific gravity	-	2.671
4.	Air voids (%)	3 – 7	5.03
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	14.6
6.	Voids filled with Asphalt, VFA (%)	65 – 80	65.6
7.	Marshal Stability (KN)	9 – 18	11.46
8.	Flow value (mm)	2 – 4	2.14

All test results of Trial mix - 1 group one, as shown in Table 4.4 satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit.

4.1.1.2. Test results and Discussions on Trial mix - 1 group Two

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity; void contents (air voids (Va), voids in the mineral aggregate (VMA), voids filled with asphalt (VFA)), stability and flow and effective asphalt content of trial mix - 1 group two.

4.1.1.2.1. Bulk specific gravity of Trial mix - 1 group Two

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.5: Test results of bulk specific gravity of Trial mix - 1 group Two

	Specimen Identification	**1**	**2**	**3**
1.	Mass in air, gm	1235.3	1240.2	1233.3
2.	Mass in water, gm	745.8	756.5	745.4
3.	Mass of surface - dry in air, gm	1236.3	1240.6	1234
4.	Volume of specimen,cm^3	490.5	484.1	488.6
5.	Bulk specific gravity , actual	2.518	2.562	2.524
	Bulk specific gravity, actual, Average (Gmb)	**2.535**		

4.1.1.2.2. Maximum specific gravity of Trial mix - 1 group Two

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.6: Test results of maximum specific gravity of Trial mix - 1 group Two

T 23^{O}C

	Specimen Identification	**1**	**2**
1.	Mass of dry sample in air, gm	593.6	639.6
2.	Mass of flask filled with water at 25 ^{O}C, gm	1590.7	1590.7
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	1960.9	1990
4.	Maximum specific gravity	2.657	2.662
	Maximum specific gravity mean value (Gmm)	**2.659**	

4.1.1.2.3. Air voids analysis of Trial mix - 1 group Two

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \left(\frac{2.659 - 2.535}{2.659}\right) \quad = \quad \mathbf{4.68}$$

4.1.1.2.4. Voids in the mineral aggregate analysis of Trial mix - 1 group Two

The voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \left(\frac{2.535 \text{ X } 95.18}{2.827}\right) \quad = \quad \mathbf{14.7}$$

4.1.1.2.5. Voids filled with asphalt (VFA) analysis of Trial mix - 1 group Two

The voids filled with asphalt (VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \left(\frac{14.7 - 4.68}{14.7}\right) \quad = \quad \mathbf{68.0}$$

4.1.1.2.6. Test results of Stability and Flow of Trial mix - 1 group Two

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y= 0.002X^2 + 1.262X – 0.069 \text{ x correlation ratio.}$$

Table 4.7: Test results of Stability and Flow of Trial mix - 1 group Two

	Specimen Identification	**1**	**2**	**3**
1.	Thickness of specimen, mm	61.0	59.0	60.0
2.	Correlation ratio	1.09	1.09	1.09
3.	Stability, Measured, KN	7.11	9.22	7.68
4.	Stability, corrected, KN	9.82	12.79	10.62
5.	Stability, corrected Average, KN	11.08		
6.	Flow, mm	2.21	1.72	2.16
7.	Flow, Average, mm	2.03		

4.1.1.2.7. Effective asphalt content of Trial mix - 1 group Two

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.82 - \left(\frac{0.81}{100}\right) X\ 95.18 \qquad = \qquad \mathbf{4.05}$$

Table 4.8: Comparison of Trial mix - 1 group two test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 1 group two
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.82
2.	Bulk specific gravity	-	2.535
3.	Maximum specific gravity	-	2.659
4.	Air voids (%)	3 – 7	4.68
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	14.7
6.	Voids filled with Asphalt, VFA (%)	65 – 80	68.0
7.	Marshal Stability (KN)	9 – 18	11.08
8.	Flow value (mm)	2 – 4	2.03

All test results of Trial mix - 1 group two, as shown in Table 4.8 satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit.

4.1.1.3. Test results and Discussions on Trial mix - 1group Three

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA)), stability and flow, and effective asphalt content of trial mix - 1 group three.

4.1.1.3.1. Bulk specific gravity of Trial mix - 1 group Three

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen’s mass in air, mass in water and mass of surface - dry in air.

Table 4.9: Test results of bulk specific gravity of Trial mix - 1 group Three

	Specimen Identification	**1**	**2**	**3**
1.	Mass in air, gm	1233.7	1240.8	1232.6
2.	Mass in water, gm	732.8	749.4	749.2
3.	Mass of surface - dry in air, gm	1234.9	1241.4	1233.0
4.	Volume of specimen,cm^3	502.1	492.0	483.8
5.	Bulk specific gravity , actual	2.457	2.522	2.548
	Bulk specific gravity, actual, Average (Gmb)	**2.509**		

4.1.1.3.2. Maximum specific gravity of Trial mix - 1 group Three

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.10: Test results of maximum specific gravity of Trial mix - 1 group Three

T 25^{O}C

	Specimen Identification	**1**	**2**
1.	Mass of dry sample in air, gm	543.8	667.5
2.	Mass of flask filled with water at 25 ^{O}C, gm	1590.7	1590.7
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	1927.7	2003.9
4.	Maximum specific gravity	2.630	2.625
	Maximum specific gravity mean value (Gmm)	**2.627**	

4.1.1.3.3. Air voids analysis of Trial mix - 1 group Three

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \frac{(2.627 - 2.509)}{2.509} = \mathbf{4.50}$$

4.1.1.3.4. Voids in the mineral aggregate analysis of Trial mix - 1 group Three

The voids in the mineral aggregate **(**VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \frac{(2.509 \text{ X } 95.18)}{2.827} = \mathbf{15.5}$$

4.1.1.3.5. Voids filled with asphalt (VFA) analysis of Trial mix - 1 group Three

The voids filled with asphalt **(**VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \frac{(15.5 - 4.50)}{15.5} = \mathbf{71.0}$$

4.1.1.3.6. Test results of Stability and Flow of Trial mix - 1 group Three

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y = 0.002X^2 + 1.262X - 0.069 \text{ x correlation ratio.}$$

Table 4.11: Test results of Stability and Flow of Trial mix - 1 group Three

	Specimen Identification	**1**	**2**	**3**
1.	Thickness of specimen, mm	62.0	62.0	61.0
2.	Correlation ratio	1.04	1.09	1.09
3.	Stability, Measured, KN	6.90	8.00	8.38
4.	Stability, corrected, KN	9.08	11.07	11.61
5.	Stability, corrected Average, KN	10.59		
6.	Flow, mm	2.18	2.32	2.03
7.	Flow, Average, mm	2.18		

4.1.1.3.7. Effective asphalt content of Trial mix - 1 group Three

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.82 - \frac{(0.31) \times 95.18}{100} = \mathbf{4.53}$$

Table 4.12: Comparison of Trial mix - 1 group three test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 1 group three
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.82
2.	Bulk specific gravity	-	2.509
3.	Maximum specific gravity	-	2.627
4.	Air voids (%)	3 – 7	4.50
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	15.5
6.	Voids filled with Asphalt (bitumen), VFA (%)	65 – 80	71.0
7.	Marshal Stability (KN)	9 – 18	10.59
8.	Flow value (mm)	2 – 4	2.18

All test results of Trial mix - 1 group three, as shown in Table 4.12 satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit.

4.1.1.4. Test results and Discussions on Trial mix - 1 group Four

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity; void contents (air voids (Va), voids in the mineral aggregate and voids filled with asphalt (VFA)), stability and flow and effective asphalt content of trial mix - 1 group four.

4.1.1.4.1. Bulk specific gravity of Trial mix - 1 group Four

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.13: Test results of bulk specific gravity of Trial mix - 1 group Four

	Specimen Identification	1	2	3
1.	Mass in air, gm	1230.0	1238.8	1240.5
2.	Mass in water, gm	748.0	753.3	741.6
3.	Mass of surface - dry in air, gm	1230.6	1239.0	1241.2
4.	Volume of specimen,cm^3	482.6	485.7	499.6
5.	Bulk specific gravity , actual	2.549	2.551	2.483
	Bulk specific gravity, actual, Average (Gmb)	**2.527**		

4.1.1.4.2. Maximum specific gravity of Trial mix - 1 group Four

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.14: Test results of maximum specific gravity of Trial mix - 1 group Four

T 25^{O}C

	Specimen Identification	1	2
1.	Mass of dry sample in air, gm	512.7	698.7
2.	Mass of flask filled with water at 25 ^{O}C, gm	1590.7	1590.7
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	1908.8	2024.4
4.	Maximum specific gravity	2.635	2.637
	Maximum specific gravity mean value (Gmm)	**2.636**	

4.1.1.4.3. Air voids analysis of Trial mix - 1 group Four

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \left(\frac{2.636 - 2.527}{2.636}\right) = \mathbf{4.11}$$

4.1.1.4.4. Voids in the mineral aggregate analysis of Trial mix - 1 group Four

The voids in the mineral aggregate **(**VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \left(\frac{2.527 \text{ X } 95.18}{2.827}\right) = \mathbf{14.9}$$

4.1.1.4.5. Void filled with asphalt (VFA) analysis of Trial mix - 1 group Four

The voids filled with asphalt **(**VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \left(\frac{14.9 - 4.11}{14.9}\right) = \mathbf{72.5}$$

4.1.1.4.6. Test results of Stability and Flow of Trial mix - 1 group Four

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y= 0.002X^2 + 1.262X – 0.069 \text{ x correlation ratio.}$$

Table 4.15: Test results of Stability and Flow of Trial mix - 1 group Four

	Specimen Identification	**1**	**2**	**3**
1.	Thickness of specimen, mm	61.0	61.0	63.0
2.	Correlation ratio	1.09	1.09	1.04
3.	Stability, Measured, KN	8.92	9.57	6.37
4.	Stability, corrected, KN	12.37	13.29	8.37
5.	Stability, corrected Average, KN	11.34		
6.	Flow, mm	2.67	2.34	1.24
7.	Flow, Average, mm	2.08		

4.1.1.4.7. Effective asphalt content of Trial mix - 1 group Four

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.82 - \frac{(0.44) \times 95.18}{100} = \mathbf{4.40}$$

Table 4.16: Comparison of Trial mix - 1 group four test results and project specification

No.	**Test Performed**	**Project Specification Limit**	**Test result of trial mix - 1 group four**
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.82
2.	Bulk specific gravity	-	2.527
3.	Maximum specific gravity	-	2.636
4.	Air voids (%)	3 – 7	4.11
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	14.9
6.	Voids filled with Asphalt, VFA (%)	65 – 80	72.5
7.	Marshal Stability (KN)	9 – 18	11.34
8.	Flow value (mm)	2 – 4	2.08

All test results of Trial mix - 1 group four, as shown in Table 4.16 satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit.

4.1.2. Test results and Discussions on Trial mix - 2

In this part, the test results on the performance of the four groups of hot mix made with different amount of crushed dust and marble waste powder are presented, analyzed and discussed.

4.1.2.1. Test results and Discussions on Trial mix - 2 group one

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in mineral aggregate and voids filled with asphalt (VFA)), stability and flow, and effective asphalt content of trial mix - 2 group one.

4.1.2.1.1. Bulk specific gravity of Trial mix - 2 group one

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.17: Test results of bulk specific gravity of Trial mix - 2 group one

	Specimen Identification	**1**	**2**	**3**
1.	Mass in air, gm	1245.3	1241.7	1227.0
2.	Mass in water, gm	755.3	741.8	745.6
3.	Mass of surface - dry in air, gm	1245.9	1242.8	1227.7
4.	Volume of specimen,cm^3	490.6	501.0	482.1
5.	Bulk specific gravity , actual	2.538	2.478	2.545
	Bulk specific gravity, actual, Average (Gmb)	**2.521**		

4.1.2.1.2. Maximum specific gravity of Trial mix - 2 group one

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.18: Test results of maximum specific gravity of Trial mix - 2 group one

T $24^{O}C$

	Specimen Identification	**1**	**2**
1.	Mass of dry sample in air, gm	540.4	600.0
2.	Mass of flask filled with water at 25 ^{O}C, gm	1590.7	1590.7
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	1925.2	1962.2
4.	Maximum specific gravity	2.625	2.626
	Maximum specific gravity mean value (Gmm)	**2.625**	

4.1.2.1.3. Air voids analysis of Trial mix - 2 group one

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \frac{(2.625 - 2.521)}{2.625} = \mathbf{3.98}$$

4.1.2.1.4. Voids in the mineral aggregate analysis of Trial mix - 2 group one

The voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \frac{(2.521 \times 95.03)}{2.827} = \mathbf{15.3}$$

4.1.2.1.5. Voids filled with asphalt (VFA) analysis of Trial mix - 2 group one

The voids filled with asphalt **(**VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \frac{(15.3 - 3.98)}{15.3} = \mathbf{73.9}$$

4.1.2.1.6. Test results of Stability and Flow of Trial mix - 2 group one

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y= 0.002X^2 + 1.262X - 0.069 \text{ x correlation ratio.}$$

Table 4.19: Test results of Stability and Flow of Trial mix - 2 group one

	Specimen Identification	**1**	**2**	**3**
1.	Thickness of specimen, mm	59.0	60.0	61.0
2.	Correlation ratio	1.09	1.04	1.14
3.	Stability, Measured, KN	9.74	7.21	8.03
4.	Stability, corrected, KN	13.53	9.50	11.62
5.	Stability, corrected Average, KN	11.55		
6.	Flow, mm	2.87	2.07	2.28
7.	Flow, Average, mm	2.41		

4.1.2.1.7. Effective asphalt content of Trial mix - 2 group one

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.97 - \left(\frac{0.38}{100}\right) X\ 95.03 \qquad = \qquad \mathbf{4.61}$$

Table 4.20: Comparison of Trial mix - 2 group one test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 2 group one
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.97
2.	Bulk specific gravity	-	2.521
3.	Maximum specific gravity	-	2.625
4.	Air voids (%)	3 – 7	3.98
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	15.3
6.	Voids filled with Asphalt, VFA (%)	65 – 80	73.9
7.	Marshal Stability (KN)	9 – 18	11.55
8.	Flow value (mm)	2 – 4	2.41

All test results of Trial mix - 2 group one, as shown in Table 4.20 satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit.

4.1.2.2. Test results and Discussions on Trial mix - 2 group Two

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA)), stability and flow, and effective asphalt content of trial mix - 2 group two.

4.1.2.2.1. Bulk specific gravity of Trial mix - 2 group Two

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.21: Test results of bulk specific gravity of Trial mix - 2 group Two

	Specimen Identification	1	2	3
1.	Mass in air, gm	1247.0	1223.6	1251.0
2.	Mass in water, gm	757.8	742.0	757.7
3.	Mass of surface - dry in air, gm	1248.3	1224.3	1251.5
4.	Volume of specimen,cm^3	490.5	482.3	493.8
5.	Bulk specific gravity , actual	2.542	2.537	2.533
	Bulk specific gravity, actual, Average (Gmb)	2.538		

4.1.2.2.2. Maximum specific gravity of Trial mix - 2 group Two

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.22: Test results of maximum specific gravity of Trial mix - 2 group Two

T $24^{O}C$

	Specimen Identification	1	2
1.	Mass of dry sample in air, gm	697.3	536.6
2.	Mass of flask filled with water at $25^{O}C$, gm	1590.7	1590.7
3.	Mass of flask filled with water and sample at $25^{O}C$, gm	2022.6	1923.0
4.	Maximum specific gravity	2.628	2.627
	Maximum specific gravity mean value (Gmm)	**2.627**	

4.1.2.2.3. Air voids analysis of Trial mix - 2 group Two

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \frac{(2.627 - 2.538)}{2.627} = \mathbf{3.41}$$

4.1.2.2.4. Voids in the mineral aggregate analysis of Trial mix - 2 group Two

The voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \left(\frac{2.538 \text{ X } 95.03}{2.827}\right) \qquad = \qquad \mathbf{14.7}$$

4.1.2.2.5. Voids filled with asphalt (VFA) analysis of Trial mix - 2 group Two

The voids filled with asphalt **(**VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \text{ x } \left(\frac{14.7 - 3.41}{14.7}\right) \qquad = \qquad \mathbf{76.8}$$

4.1.2.2.6. Test results of Stability and Flow of Trial mix - 2 group Two

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y= 0.002X^2 + 1.262X - 0.069 \text{ x correlation ratio.}$$

Table 4.23: Test results of Stability and Flow of Trial mix - 2 group Two

	Specimen Identification	1	2	3
1.	Thickness of specimen, mm	59.0	59.0	60.0
2.	Correlation ratio	1.09	1.14	1.09
3.	Stability, Measured, KN	8.33	7.92	8.82
4.	Stability, corrected, KN	11.53	11.46	12.23
5.	Stability, corrected Average, KN	11.74		
6.	Flow, mm	1.76	1.97	2.17
7.	Flow, Average, mm	1.97		

4.1.2.2.7. Effective asphalt content of Trial mix - 2 group Two

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.97 - \left(\frac{0.41}{100}\right) \text{ X } 95.03 \qquad = \qquad \mathbf{4.58}$$

Table 4.24: Comparison of Trial mix - 2 group two test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 2 group Two
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.97
2.	Bulk specific gravity	-	2.538
3.	Maximum specific gravity	-	2.627
4.	Air voids (%)	3 – 7	3.41
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	14.7
6.	Voids filled with Asphalt, VFA (%)	65 – 80	76.8
7.	Marshal Stability (KN)	9 – 18	11.74
8.	Flow value (mm)	2 – 4	1.97

All test results of Trial mix - 2 group Two, as shown in Table 4.24 satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit.

4.1.2.3. Test results and Discussions on Trial mix - 2 group Three

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in the mineral aggregate and voids filled with asphalt (VFA)), stability and flow, and effective asphalt content of trial mix - 2 group three.

4.1.2.3.1. Bulk specific gravity of Trial mix - 2 group Three

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.25: Test results of bulk specific gravity of Trial mix - 2 group Three

	Specimen Identification	1	2	3
1.	Mass in air, gm	1245.4	1247.3	1243.0
2.	Mass in water, gm	758.6	747.0	742.3
3.	Mass of surface - dry in air, gm	1247.0	1248.1	1244.4
4.	Volume of specimen,cm^3	488.4	501.1	502.1
5.	Bulk specific gravity , actual	2.550	2.489	2.476
	Bulk specific gravity, actual, Average (Gmb)	**2.505**		

4.1.2.3.2. Maximum specific gravity of Trial mix - 2 group Three

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.26: Test results of maximum specific gravity of Trial mix - 2 group Three

T 25^{O}C

	Specimen Identification	1	2
1.	Mass of dry sample in air, gm	635.9	574.5
2.	Mass of flask filled with water at 25 ^{O}C, gm	1632.9	1632.9
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	2027.8	1989.0
4.	Maximum specific gravity	2.639	2.630
	Maximum specific gravity mean value (Gmm)	**2.635**	

4.1.2.3.3. Air voids analysis of Trial mix - 2 group Three

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \frac{(2.635 - 2.505)}{2.635} \quad = \quad \mathbf{4.93}$$

4.1.2.3.4. Voids in the mineral aggregate analysis of Trial mix - 2 group Three

The voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \frac{(2.505 \text{ X } 95.03)}{2.827} \quad = \quad \mathbf{15.8}$$

4.1.2.3.5. Voids filled with asphalt (VFA) analysis of Trial mix - 2 group Three

The voids filled with asphalt (VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \frac{(15.8 - 4.93)}{15.8} \quad = \quad \mathbf{68.8}$$

4.1.2.3.6. Test results of Stability and Flow of Trial mix - 2 group Three

The measured stability of a specimen multiplied by the thickness of the specimen equals the corrected stability. Stability correction is calculated by:

$Y= 0.002X^2 + 1.262X – 0.069$ x correlation ratio.

Table 4.27: Test results of Stability and Flow of Trial mix - 2 group Three

	Specimen Identification	**1**	**2**	**3**
1.	Thickness of specimen, mm	60.0	61.0	61.0
2.	Correlation ratio	1.09	1.04	1.04
3.	Stability, Measured, KN	8.57	5.99	6.19
4.	Stability, corrected, KN	11.87	7.86	8.13
5.	Stability, corrected Average, KN	9.29		
6.	Flow, mm	2.55	2.10	2.09
7.	Flow, Average, mm	2.25		

4.1.2.3.7. Effective asphalt content of Trial mix - 2 group Three

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.97 - \frac{(0.53) \times 95.03}{100} = \mathbf{4.47}$$

Table 4.28: Comparison of Trial mix - 2 group three test results and project specification

No.	**Test Performed**	**Project Specification Limit**	**Test result of trial mix - 2 group Three**
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.97
2.	Bulk specific gravity	-	2.505
3.	Maximum specific gravity	-	2.635
4.	Air voids (%)	3 – 7	4.93
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	15.8
6.	Voids filled with Asphalt, VFA (%)	65 – 80	68.8
7.	Marshal Stability (KN)	9 – 18	9.29
8.	Flow value (mm)	2 – 4	2.25

All test results of Trial mix - 2 group Three, as shown in Table 4.28 satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit.

4.1.2.4. Test results and Discussions on Trial mix - 2 group Four

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA)) , stability and flow, and effective asphalt content of trial mix - 2 group four.

4.1.2.4.1. Bulk specific gravity of Trial mix - 2 group Four

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.29: Test results of bulk specific gravity of Trial mix - 2 group Four

	Specimen Identification	1	2	3
1.	Mass in air, gm	1249.0	1244.0	1240.9
2.	Mass in water, gm	755.8	747.0	744.3
3.	Mass of surface - dry in air, gm	1249.5	1244.5	1241.7
4.	Volume of specimen,cm^3	493.7	497.5	497.4
5.	Bulk specific gravity , actual	2.530	2.501	2.495
	Bulk specific gravity, actual, Average (Gmb)	**2.508**		

4.1.2.4.2. Maximum specific gravity of Trial mix - 2 group Four

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.30: Test results of maximum specific gravity of Trial mix - 2 group four

T 25^{O}C

	Specimen Identification	1	2
1.	Mass of dry sample in air, gm	566.5	650.5
2.	Mass of flask filled with water at 25 ^{O}C, gm	1632.9	1632.9
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	1985.8	2041.3
4.	Maximum specific gravity	2.652	2.687
	Maximum specific gravity mean value (Gmm)	**2.669**	

4.1.2.4.3. Air voids analysis of Trial mix - 2 group Four

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \left(\frac{2.669 - 2.508}{2.669}\right) = \mathbf{6.03}$$

4.1.2.4.4. Voids in the mineral aggregate analysis of Trial mix - 2 group Four

The voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \left(\frac{2.508 \text{ X } 95.03}{2.827}\right) = \mathbf{15.7}$$

4.1.2.4.5. Void filled with asphalt (VFA) analysis of Trial mix - 2 group Four

The voids filled with asphalt (VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \left(\frac{15.7 - 6.03}{15.7}\right) = \mathbf{61.5}$$

4.1.2.4.6. Test results of Stability and Flow of Trial mix - 2 group Four

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y= 0.002X^2 + 1.262X – 0.069 \text{ x correlation ratio.}$$

Table 4.31: Test results of Stability and Flow of Trial mix - 2 group Four

	Specimen Identification	**1**	**2**	**3**
1.	Thickness of specimen, mm	60.0	60.0	61.0
2.	Correlation ratio	1.09	1.04	1.04
3.	Stability, Measured, KN	8.86	7.19	7.04
4.	Stability, corrected, KN	12.28	9.47	9.27
5.	Stability, corrected Average, KN	10.34		
6.	Flow, mm	1.95	2.13	1.64
7.	Flow, Average, mm	1.91		

4.1.2.4.7. Effective asphalt content of Trial mix - 2 group Four

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.97 - \frac{(1.06) \times 95.03}{100} \qquad = \qquad \mathbf{3.96}$$

Table 4.32: Comparison of Trial mix - 2 group four test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 2 group Four
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.97
2.	Bulk specific gravity	-	2.508
3.	Maximum specific gravity	-	2.669
4.	Air voids (%)	3 – 7	6.03
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	15.7
6.	Voids filled with Asphalt, VFA (%)	65 – 80	61.5
7.	Marshal Stability (KN)	9 – 18	10.34
8.	Flow value (mm)	2 – 4	1.91

This trial mix (Trial mix - 2 group four) test result as shown in Table 4.32 the air voids, void filled with asphalt (VFA) and flow value do not satisfy the specified requirement of Maytsebri – Shire road upgrading project specifications limit. The allowable percentage of air voids in laboratory specimen is between 3 - 5 percent (Manual series – 22, 1998). The test result of trial mix - 2 group four, an air void content that is too high provides:

- Water and air can easily enter in to the pavement, causing oxidation and disintegration.
- Early hardening of asphalt followed by cracking or disintegration, it causes lack of durability (The durability of an asphalt pavement is a function of the air void content).
- Early aging of asphalt followed by Fatigue cracking. Air voids has a significant effect on Fatigue resistance (Manual series – 22, 1998).

The voids filled with Asphalt (VFA) and Flow that is too low value provides:

- The mix will be too brittle and rigid (not durable).

Adjustment of a trial mix (Trial mix - 2 group four) in order to meet design criteria (the specified requirement of Maytsebri – Shire road upgrading project specification) should be done. To do so:

- The air void content should be reduced by increasing the mineral dust content in to the asphalt concrete mix. It may also be necessary, however, to adjust the aggregate gradation.
- The percent voids filled with asphalt (VFA) and flow should be increased by increasing the asphalt (bitumen) content of the asphalt concrete mix.

4.1.3. Test results and Discussions on Trial mix - 3

In this part, the test results on the performance of the four groups of hot mix asphalt made with different amount of crushed dust and marble waste powder are presented, analyzed and discussed.

4.1.3.1. Test results and Discussions on Trial mix - 3 group one

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in the mineral aggregate and voids filled with asphalt (VFA)), stability and flow, and effective asphalt content of trial mix – 3 group one.

4.1.3.1.1. Bulk specific gravity of Trial mix - 3 group one

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.33: Test results of bulk specific gravity of Trial mix - 3 group one

	Specimen Identification	**1**	**2**	**3**
1.	Mass in air, gm	1242.4	1220.5	1203.6
2.	Mass in water, gm	754.2	743.5	752.0
3.	Mass of surface - dry in air, gm	1259.3	1238.0	1237.9
4.	Volume of specimen,cm^3	505.1	494.5	485.9
5.	Bulk specific gravity , actual	2.460	2.468	2.477
	Bulk specific gravity, actual, Average (Gmb)		**2.468**	

4.1.3.1.2. Maximum specific gravity of Trial mix - 3 group one

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.34: Test results of maximum specific gravity of Trial mix - 3 group one

T 23^{O}C

	Specimen Identification	1	2
1.	Mass of dry sample in air, gm	650.0	576.5
2.	Mass of flask filled with water at 25 ^{O}C, gm	1598.3	1598.3
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	1995.2	1950.3
4.	Maximum specific gravity	2.567	2.567
	Maximum specific gravity mean value (Gmm)	**2.567**	

4.1.3.1.3. Air voids analysis of Trial mix - 3 group one

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \left(\frac{2.567 - 2.468}{2.567}\right) = \mathbf{3.85}$$

4.1.3.1.4. Voids in the mineral aggregate analysis of Trial mix - 3 group one

The voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \left(\frac{2.468 \times 94.88}{2.827}\right) = \mathbf{17.2}$$

4.1.3.1.5. Voids filled with asphalt (VFA) analysis of Trial mix - 3 group one

The voids filled with asphalt (VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \left(\frac{17.2 - 3.85}{17.2}\right) = \mathbf{77.54}$$

4.1.3.1.6. Test results of Stability and Flow of Trial mix - 3 group one

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y = 0.002X^2 + 1.262X - 0.069 \times \text{correlation ratio.}$$

Table 4.35: Test results of Stability and Flow of Trial mix - 3 group one

	Specimen Identification	1	2	3
1.	Thickness of specimen, mm	66.0	65.0	65.0
2.	Correlation ratio	1.04	1.09	1.09
3.	Stability, Measured, KN	4.87	7.78	4.75
4.	Stability, corrected, KN	6.37	10.76	6.51
5.	Stability, corrected Average, KN	7.88		
6.	Flow, mm	2.88	3.00	2.79
7.	Flow, Average, mm	2.89		

4.1.3.1.7. Effective asphalt content of Trial mix - 3 group one

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 5.12 - \left(\frac{0.469}{100}\right) \times 94.88 \quad = \quad \mathbf{4.68}$$

Table 4.36: Comparison of Trial mix - 3 group one test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 3 group one
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	5.12
2.	Bulk specific gravity	-	2.468
3.	Maximum specific gravity	-	2.567
4.	Air voids (%)	3 – 7	3.85
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	17.2
6.	Voids filled with Asphalt, VFA (%)	65 – 80	77.54
7.	Marshal Stability (KN)	9 – 18	7.88
8.	Flow value (mm)	2 – 4	2.89

This trial mix (Trial mix – 3 group one) test result as shown in Table 4.36 voids in the mineral aggregate (VMA) and Stability value do not satisfy the specified requirement of Maytsebri – Shire road upgrading project specifications limit. The allowable percentage of air voids in laboratory specimen is between 3 - 5 percent (Manual series – 22, 1998). The test results of trial mix - 3 group one, an asphalt (bitumen binder) content that is too high provides:

- Wash boarding, rutting and flushing or bleeding (it affects the stability).
- Low skid resistance.

Coarse Aggregate content is too high provides:

- Hard to compact. It causes to increase the thickness of the specimen. The test result of the average thickness of specimen is 65.3mm.The marshal method uses standard test specimen thickness is 63.5 (Manual series – 2, 1997). Harsh mixtures (mixtures containing excessive coarse aggregate) have a tendency to segregate during handling and also may be difficult to compact (Manual series – 22, 1998). Poor workability is difficult to place and compact.

Void in the mineral aggregate (VMA) content that is too high provides:

- The mixture may stability problem.

Stability value that is too low provides:

- Mix may be dry or gummy, hard to handle, not durable.

Adjustment of a trial mix (Trial mix - 3 group one) in order to meet design criteria (the specified requirement of Maytsebri - Shire road upgrading project specification) should be done. To do so:

- The trial specimen height falls outside the project specification limit the amount of aggregate used for the specimen adjusted.

$$\text{Adjustment of mass of aggregate} = \frac{63.5\ (\text{mass of aggregate used})}{\text{Specimen height (mm) obtained}}$$

- The percent voids in the mineral aggregate (VMA) should be reduced by increasing the amount of mineral fillers.
- The stability value should be increased by increasing the amount of crushed material (using more angular with rough surface aggregate).
- The other three trial mixes could not be molded in the compaction mold, since the mix is harsh. The mix is harsh because it contains high percentage of coarse aggregate and asphalt content. This has a tendency to segregate during handling and also may be difficult to compact. It is the result of poor workability.

4.1.4. Test results and Discussions on Trial mix - 4

In this part, the test results on the performance of the group of hot mix asphalt made with 2% cement, 4% crushed dust are presented, analyzed and discussed.

4.1.4.1. Test results and Discussions on Trial mix – 4

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA)) , stability and flow, and effective asphalt content of trial mix - 4.

4.1.4.1.1. Bulk specific gravity of Trial mix - 4

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.37: Test results of bulk specific gravity of Trial mix - 4

	Specimen Identification	**1**	**2**	**3**
1.	Mass in air, gm	1236.6	1235.1	1232.4
2.	Mass in water, gm	757.6	757.0	755.6
3.	Mass of surface - dry in air, gm	1237.2	1235.4	1233.1
4.	Volume of specimen,cm^3	479.6	478.4	477.5
5.	Bulk specific gravity , actual	2.578	2.582	2.581
	Bulk specific gravity, actual, Average (Gmb)	**2.580**		

4.1.4.1.2. Maximum specific gravity of Trial mix - 4

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.38: Test results of maximum specific gravity of Trial mix - 4

T 25^{O}C

	Specimen Identification	**1**	**2**
1.	Mass of dry sample in air, gm	614.3	620.2
2.	Mass of flask filled with water at 25 ^{O}C, gm	1632.9	1632.9
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	2021.0	2021.5
4.	Maximum specific gravity	2.716	2.678
	Maximum specific gravity mean value (Gmm)	**2.697**	

4.1.4.1.3. Air voids analysis of Trial mix - 4

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \frac{(2.697 - 2.580)}{2.697} = \mathbf{4.32}$$

4.1.4.1.4. Voids in the mineral aggregate (VMA) analysis of Trial mix - 4

The voids in the mineral aggregate **(**VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \frac{(2.580 \times 95.18)}{2.827} = \mathbf{13.1}$$

4.1.4.1.5. Voids filled with asphalt (VFA) analysis of Trial mix - 4

The voids filled with asphalt **(**VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \frac{(13.1 - 4.32)}{13.1} = \mathbf{67.1}$$

4.1.4.1.6. Test results of Stability and Flow of Trial mix - 4

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y= 0.002X^2 + 1.262X - 0.069 \text{ x correlation ratio.}$$

Table 4.39: Test results of Stability and Flow of Trial mix - 4

	Specimen Identification	1	2	3
1.	Thickness of specimen, mm	58.0	58.0	57.0
2.	Correlation ratio	1.14	1.14	1.14
3.	Stability, Measured, KN	12.94	10.39	9.78
4.	Stability, corrected, KN	18.92	15.12	14.21
5.	Stability, corrected Average, KN	16.08		
6.	Flow, mm	3.31	2.20	2.82
7.	Flow, Average, mm	2.78		

4.1.4.1.7. Effective asphalt content of Trial mix - 4

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.82 - \left(\frac{1.371}{100}\right) \text{X } 95.18 \qquad = \qquad \mathbf{3.51}$$

Table 4.40: Comparison of Trial mix - 4 test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 4
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.82
2.	Bulk specific gravity	-	2.580
3.	Maximum specific gravity	-	2.697
4.	Air voids (%)	3 – 7	4.32
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	13.1
6.	Voids filled with Asphalt, VFA (%)	65 – 80	67.1
7.	Marshal Stability (KN)	9 – 18	16.08
8.	Flow value (mm)	2 – 4	2.78

All test results of Trial mix - 4, as shown Table 4.40 satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit.

4.1.5. Test results and Discussions on Trial mix - 5

In this part, the test results on the performance of the group of hot mix asphalt made with 6% cement, are presented, analyzed and discussed.

4.1.5.1. Test results and Discussions on Trial mix - 5

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA)) , stability and flow, and effective asphalt content of trial mix - 5.

4.1.5.1.1. Bulk specific gravity of Trial mix - 5

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.41: Test results of bulk specific gravity of Trial mix - 5

	Specimen Identification	1	2	3
1.	Mass in air, gm	1231.6	1235.9	1230.7
2.	Mass in water, gm	757.2	762.0	755.1
3.	Mass of surface - dry in air, gm	1232.4	1236.4	1231.4
4.	Volume of specimen, cm^3	475.2	474.4	476.3
5.	Bulk specific gravity , actual	2.592	2.605	2.584
	Bulk specific gravity, actual, Average (Gmb)		**2.594**	

4.1.5.1.2. Maximum specific gravity of Trial mix - 5

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.42: Test results of maximum specific gravity of Trial mix - 5

T 25^{O}C

	Specimen Identification	1	2
1.	Mass of dry sample in air, gm	556.2	637.3
2.	Mass of flask filled with water at 25 ^{O}C, gm	1632.9	1632.9
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	1983.5	2029.7
4.	Maximum specific gravity	2.705	2.650
	Maximum specific gravity mean value (Gmm)	**2.678**	

4.1.5.1.3. Air voids analysis of Trial mix - 5

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \frac{(2.678 - 2.594)}{2.678} = \mathbf{3.15}$$

4.1.5.1.4. Voids in the mineral aggregate (VMA) analysis of Trial mix - 5

The Voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \left(\frac{2.594 \text{ X } 95.18}{2.827}\right) = \mathbf{12.7}$$

4.1.5.1.5. Voids filled with asphalt (VFA) analysis of Trial mix - 5

The voids filled with asphalt **(**VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \text{ x } \left(\frac{12.7 - 3.15}{12.7}\right) = \mathbf{75.2}$$

4.1.5.1.6. Test results of Stability and Flow of Trial mix - 5

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y = 0.002X^2 + 1.262X - 0.069 \text{ x correlation ratio.}$$

Table 4.43: Test results of Stability and Flow of Trial mix - 5

	Specimen Identification	**1**	**2**	**3**
1.	Thickness of specimen, mm	58.0	57.0	57.0
2.	Correlation ratio	1.14	1.14	1.14
3.	Stability, Measured, KN	8.68	10.03	9.69
4.	Stability, corrected, KN	12.58	14.58	14.08
5.	Stability, corrected Average, KN	13.75		
6.	Flow, mm	1.64	2.26	3.02
7.	Flow, Average, mm	2.31		

4.1.5.1.7. Effective asphalt content of Trial mix - 5

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.82 - \left(\frac{1.09}{100}\right) \text{ X } 95.18 = \mathbf{3.79}$$

Table 4.44: Comparison of Trial mix - 5 test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 5
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.82
2.	Bulk specific gravity	-	2.594
3.	Maximum specific gravity	-	2.678
4.	Air voids (%)	3 – 7	3.15
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	12.7
6.	Voids filled with Asphalt, VFA (%)	65 – 80	75.2
7.	Marshal Stability (KN)	9 – 18	13.75
8.	Flow value (mm)	2 – 4	2.31

This trial mix (Trial mix - 5) test result as shown in Table 4.44 the air voids, voids in the mineral aggregate (VMA) do not satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit. The allowable percentage of air voids in laboratory specimen is between 3 - 5 percent (Manual series – 22, 1998). An air void content that is too low provides:

- Mix may be dry or gummy, hard to handle, not durable.

The VMA value that is to low provides:

- There will be no space around the aggregate particle this results durability problem.

Adjustment of a trial mix (Trial mix - 5) in order to meet design criteria (the specified requirement of Maytsebri – Shire road upgrading project specification) should be done. To do so:

- The air voids content should be increased by increasing the amount of crushed material and /or decreasing the amount of material passing the 0.075mm (NO.200) sieve.
- The percent voids in the mineral aggregate (VMA) content should be increased by adjustment of the gradation or possibly changing the shape or texture of the intermediate portion of the blended aggregates.

4.1.6. Test results and Discussions on Trial mix - 6

In this part, the test results on the performance of the group of hot mix asphalt made with 6% marble waste powder are presented, analyzed and discussed.

4.1.6.1. Test results and Discussions on Trial mix - 6

Testing for this part was conducted to the determination of bulk specific gravity, maximum specific gravity, void contents (air voids (Va), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA)) , stability and flow, and effective asphalt content of trial mix - 6.

4.1.6.1.1. Bulk specific gravity of Trial mix - 6

The freshly compacted specimens have cooled to room temperature. The bulk specific gravity (ASTM D 2726 OR D 1188 /AASHTO T 166) of each compacted specimen is determined by weighing specimen's mass in air, mass in water and mass of surface - dry in air.

Table 4.45: Test results of bulk specific gravity of Trial mix - 6

	Specimen Identification	**1**	**2**	**3**
1.	Mass in air, gm	1245.4	1235.9	1232.5
2.	Mass in water, gm	748.1	759.4	755.9
3.	Mass of surface - dry in air, gm	1246.9	1236.7	1233.1
4.	Volume of specimen,cm^3	498.8	477.3	477.2
5.	Bulk specific gravity , actual	2.497	2.589	2.583
	Bulk specific gravity, actual, Average (Gmb)		**2.556**	

4.1.6.1.2. Maximum specific gravity of Trial mix - 6

The maximum specific gravity of the hot mix asphalt specimen can be determined for each asphalt content by ASTM D 2041/AASHTO T 209.

Table 4.46: Test results of maximum specific gravity of Trial mix - 6

T 25^{O}C

	Specimen Identification	**1**	**2**
1.	Mass of dry sample in air, gm	591.2	650.0
2.	Mass of flask filled with water at 25 ^{O}C, gm	1632.9	1632.9
3.	Mass of flask filled with water and sample at 25 ^{O}C, gm	2002.6	2029.4
4.	Maximum specific gravity	2.669	2.564
	Maximum specific gravity mean value (Gmm)	**2.617**	

4.1.6.1.3. Air voids analysis of Trial mix - 6

The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture (zero voids).

$$= 100 \times \frac{(2.617 - 2.556)}{2.617} = \mathbf{2.31}$$

4.1.6.1.4. Voids in the mineral aggregate (VMA) analysis of Trial mix - 6

The voids in the mineral aggregate (VMA) is calculated by subtracting the volume of the aggregate, determined by its bulk specific gravity, from the bulk volume of the compacted paving mixture.

$$= 100 - \frac{(2.556 \text{ X } 95.18)}{2.827} = \mathbf{13.9}$$

4.1.6.1.5. Void filled with asphalt (VFA) analysis of Trial mix - 6

The void filled with asphalt **(**VFA) is calculated by subtracting the air voids from the VMA and dividing by the VMA, and expressing the value as a percentage.

$$= 100 \times \frac{(13.9 - 2.31)}{13.9} = \mathbf{83.4}$$

4.1.6.1.6. Test results of Stability and Flow of Trial mix - 6

The measured stability of a specimen multiplied by the ratio for the thickness of the specimen to get the corrected stability. Stability correction is calculated by:

$$Y= 0.002X^2 + 1.262X - 0.069 \text{ x correlation ratio.}$$

Table 4.47: Test results of Stability and Flow of Trial mix - 6

	Specimen Identification	1	2	3
1.	Thickness of specimen, mm	61.0	58.0	57.0
2.	Correlation ratio	1.04	1.14	1.14
3.	Stability, Measured, KN	7.25	8.69	9.13
4.	Stability, corrected, KN	9.55	12.60	13.25
5.	Stability, corrected Average, KN	11.80		
6.	Flow, mm	1.71	3.71	3.15
7.	Flow, Average, mm	2.86		

4.1.6.1.7. Effective asphalt content of Trial mix - 6

Effective asphalt content is calculated by subtracting the amount of absorbed asphalt, multiplied by the percentage of aggregate, from the total asphalt content.

$$= 4.82 - \left(\frac{0.142}{100}\right) \times 95.18 = \mathbf{4.68}$$

Table 4.48: Comparison of Trial mix - 6 test results and project specification

No.	Test Performed	Project Specification Limit	Test result of trial mix - 6
1.	Bitumen, % by weight of total mix (%) Including tolerance.	5 – 7	4.82
2.	Bulk specific gravity	-	2.556
3.	Maximum specific gravity	-	2.617
4.	Air voids (%)	3 – 7	2.31
5.	Voids in mineral Aggregate, VMA (%)	13 – 16	13.9
6.	Voids filled with Asphalt, VFA (%)	65 – 80	83.4
7.	Marshal Stability (KN)	9 – 18	11.8
8.	Flow value (mm)	2 – 4	2.86

This trial mix (Trial mix - 6) test result as shown in Table 4.48 the air voids, voids filled with asphalt (VFA) do not satisfy the specified requirement of Maytsebri – Shire road upgrading project specification limit. The allowable percentage of air voids in laboratory specimen is between 3 - 5 percent (Manual series – 22, 1998). The test results of trial mix - 6, an air void content that is too low provides:

- Mix may be dry or gummy, hard to handle, not durable.

The VFA value that is too high provides;

- The mix will generally yield a plastic. This causes low skid resistance.

Adjustment of a trial mix (Trial mix - 6) in order to meet design criteria (the specified requirement of Maytsebri – Shire road upgrading project specification) should be done. To do so:

- The air voids content should be increased by increasing the amount of crushed material and /or decreasing the amount of material passing the 0.075mm (NO.200) sieve.
- The air voids content should be increased by adjusting the aggregate gradation; the aggregate gradation should be adjusted by adding coarser or finer aggregate.
- The percent voids filled with asphalt should be reduced by decreasing the asphalt content of the mix. A VFA is too high, however, will generally yield a plastic mix.

Test Property curves for hot mix asphalt

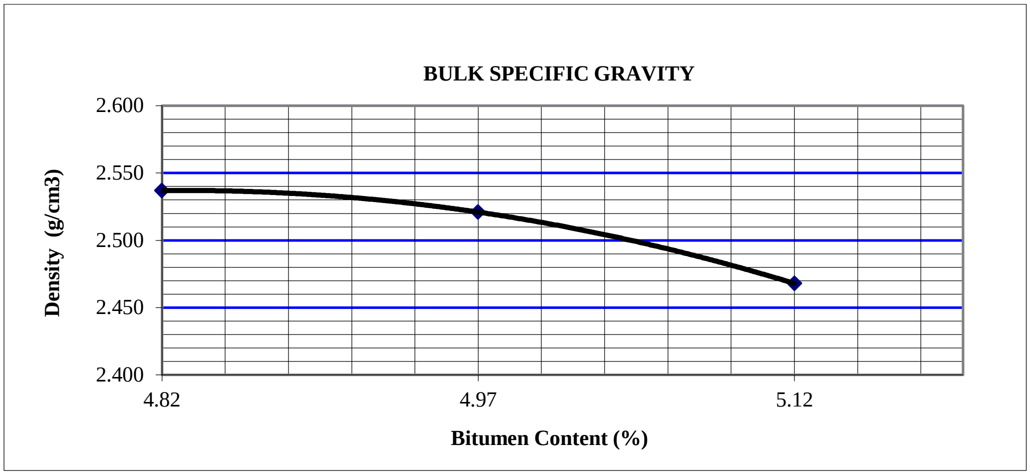

Fig 4.1: Bulk density VS. Bitumen content

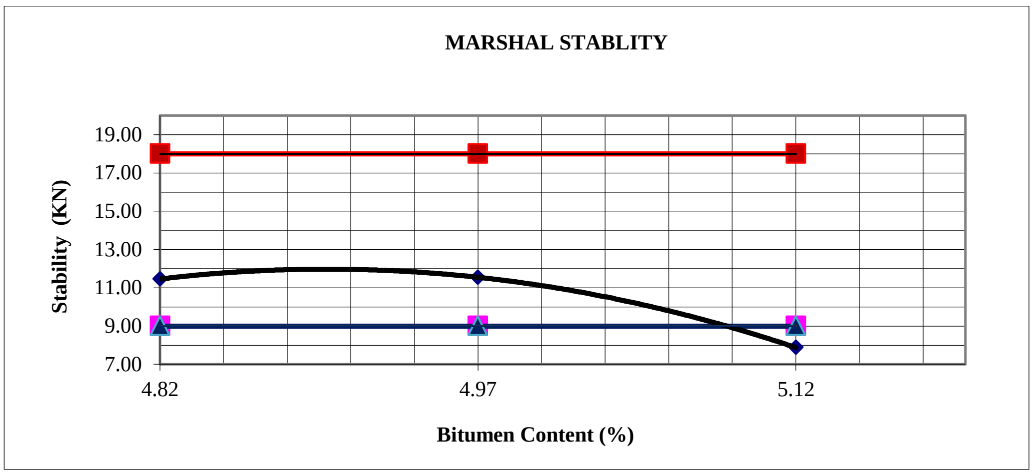

Fig 4.2: Stability VS. Bitumen content

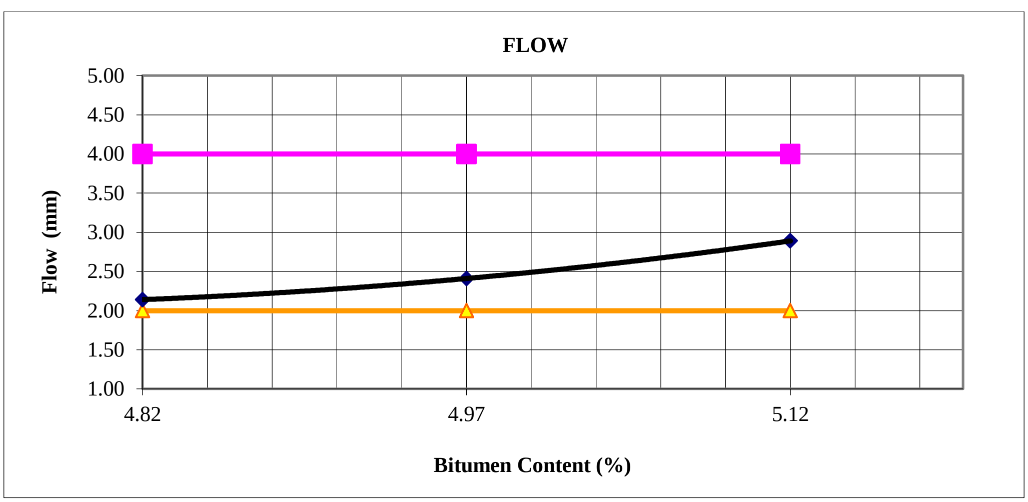

Fig 4.3: Flow VS. Bitumen content

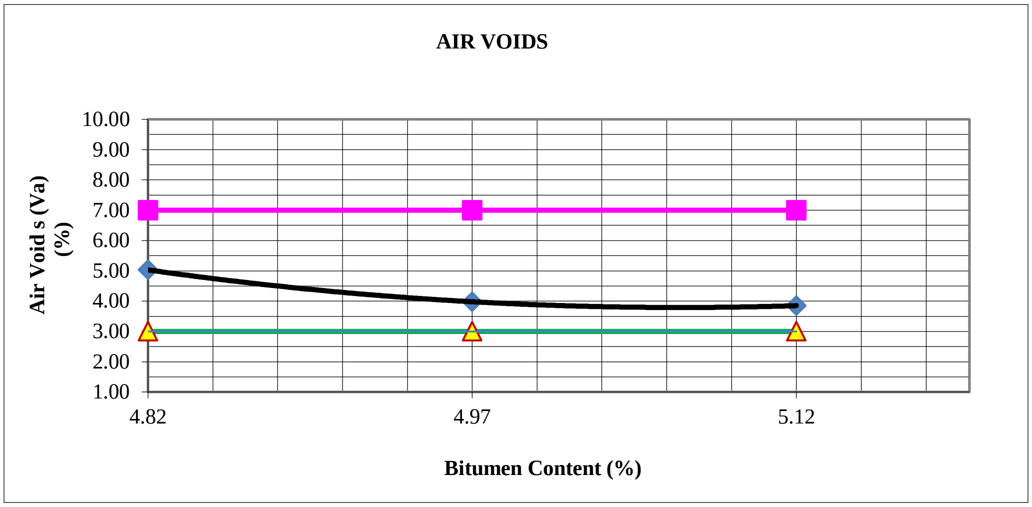

Fig 4.4: Air Voids VS. Bitumen content

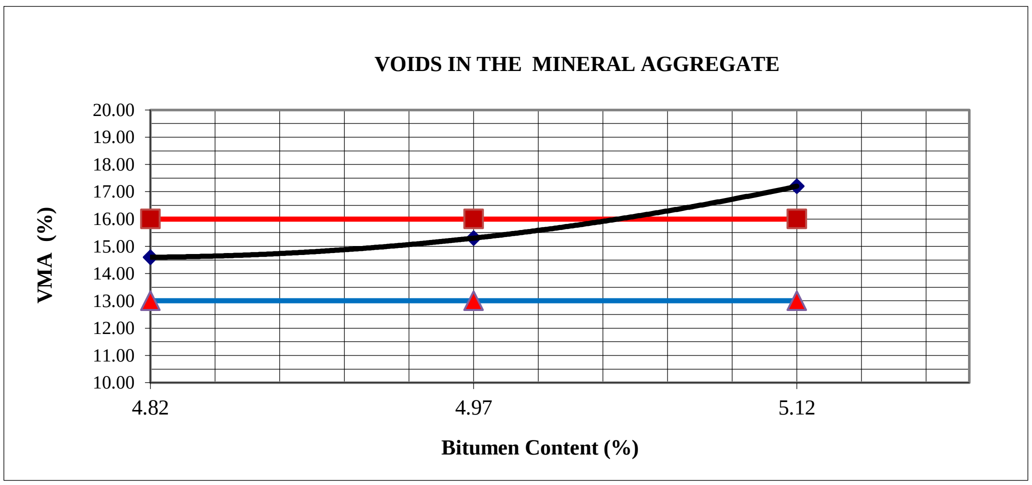

Fig 4.5: Voids in the Mineral aggregate VS. Bitumen content

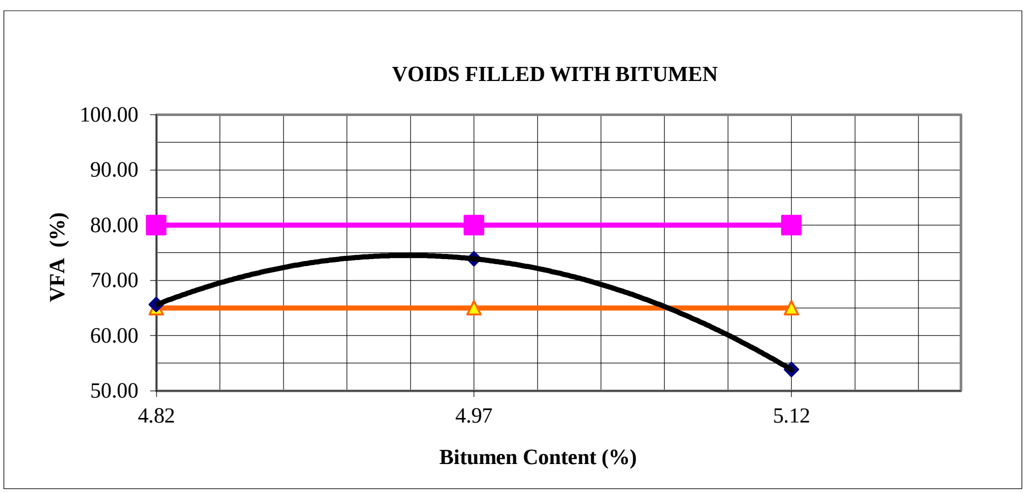

Fig 4.6: Voids filled with bitumen VS. Bitumen content

Table 4.49: Test results of Indirect tensile strength and E – modulus

Filler Type	Sample No.	Specimen height (mm)	Specimen diameter (mm)	Measured maximum load (N)	Indirect tensile strength	E- modulus (MPa)
Cement	1	58	102.3	12940	1387.83	8566.76
	2	58	101.8	10390	1119.81	6930.85
	3	57	101.6	9780	1074.67	6655.49
Average Values					1194.10	7384.04
Marble waste powder	1	61	101.3	8280	852.70	5301.47
	2	60	101.2	8070	845.76	5259.14
	3	59	101.5	8490	902.18	5603.32
Average Values					866.88	5387.98

From the above table it is observed that a particular temperature the mixture made with marble waste powder as a filler has lower tensile strength and E – Modulus as compared to cement.

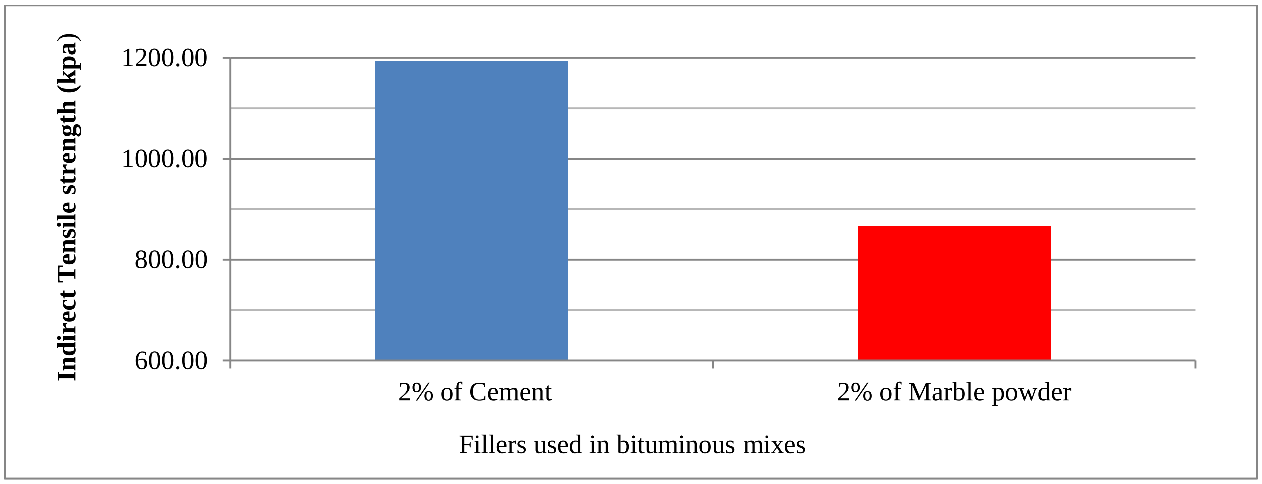

Fig 4.7: Variation of IDT strength for mixes with cement and marble waste powder

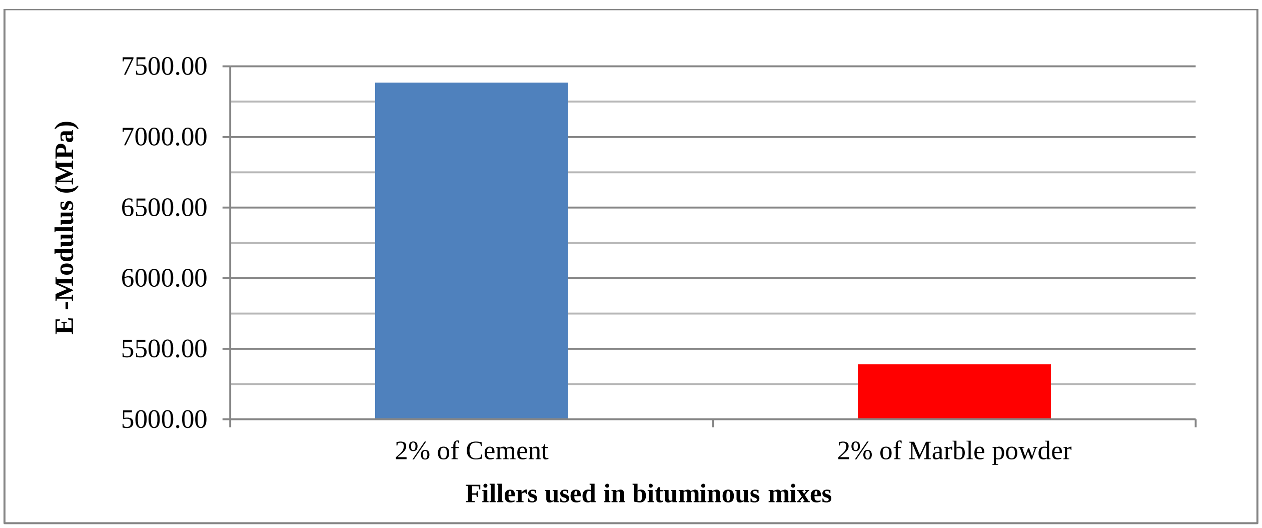

Fig 4.8: Variation of E – Modulus for mixes with cement and marble waste powder

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Construction industry by itself is a great concern related to environmental pollution and also related to degradation of an environment due to consumptions of large amount of non - renewable natural resources.

Recycling of industrial wastes is one of the solutions given attention worldwide for environmental protection and for economic and sustainable use of resources.

The main objective of this research is to investigate the performance of using marble waste powder as a filler in hot asphalt mixture. Based on the results of laboratory tests and analysis the following conclusions are made.

1. Based on the results of hot mix asphalt concrete test, the amount of marble waste powder at 2%, 2.5%, 3%, and 3.5% by weight with optimum binder content 4.82% results fulfill the specified requirements of Maytsebri – Shire road upgrading project specification.
2. Based on the results of hot mix asphalt concrete test, the amount of marble waste powder at 2%, 2.5%, and 3% by weight with optimum binder content 4.97% results fulfill the specified requirements of Maytsebri – Shire road upgrading project specification.
3. Using marble waste powder as a filler in hot asphalt concrete mixtures led to produce lighter mixtures almost with higher percentage of air voids as compared with corresponding mixtures containing Portland cement.
4. The highest stability value was obtained from marble waste powder content at 2% and optimum binder content 4.82%. The stability values from the highest to the lowest user from 2%, 3.5%, 2.5% and 3%. Therefore, it is considered that the hot mix asphalt concrete sample with 2% marble waste powder is more durable to atmospheric conditions.
5. The highest stability value was obtained from marble waste powder content at 2.5% and optimum binder content 4.97%. The stability values from the highest to the lowest user from 2.5%, 2% and 3%. Therefore, it is considered that the hot mix asphalt concrete sample with 2.5% marble waste powder is more durable to atmospheric conditions.
6. The effective asphalt content in the hot asphalt concrete mix provides the required film thickness around the aggregate particles. It is the available film thickness that determines

flexibility and durability of mixtures. Mixes made with marble waste powder have higher effective asphalt content as compared to mixes containing Portland cement. Thus mixtures containing marble waste powder have higher film thickness around aggregate particles than mixes containing Portland cement and have high durability.

7. It can be concluded that marble waste powder can be successfully used in hot asphalt concrete pavements as a filler which also contributes to the protection of the environment and provide economic benefits.
8. Generally, different characteristics of bituminous hot mixtures were observed when the fillers in the mixture were varied by type and content. This indicates that, mineral fillers are significant ingredients affecting mixture properties.
9. The highest VFA value obtained from 2.5% marble waste powder and 4.97% optimum binder content. If the VFA is too high, the durability and stability of asphalt concrete are also strong. VFA controls plasticity, durability and friction coefficient of the mixtures and also provides a final asphalt coating around the aggregate particles.
10. It is generally concluded that the marble waste powder can effectively be used as a filler in paving mixes in place of most commonly used fillers such as cement and stone dust. Use marble waste in paving mixes may give a solution to the marble waste utilization and disposal problems and also give a means to make the environment safe and clean.

Road construction is an important method in which waste materials can be recycled in the field of construction. Using waste materials in road construction would prevent excessive use of natural raw materials, conserving them for later use or for other purposes in the global economy. Thus it can be concluded that marble waste powder should be used in bituminous hot mixtures as a filler will result.

5.2. Recommendations

Each region of the world should play role in environmental protection and sustainable use of natural resources. Ethiopian construction industries also need to benefit from recycling of waste materials as other countries did.

Therefore based on the study the following recommendations are forwarded.

1. The incorporation of marble sludge wastes in asphalt concrete production has proven to be safe for health and environmentally friendly.
2. The incorporation of marble sludge wastes reduces natural resource consumption and reduces landfill occupation areas.
3. Its usage will decrease the side effects of pollution caused by the accumulations of tons of waste in situ.
4. It is recommended for local authorities to permit using marble waste powder in asphalt concrete pavements depending on the results of this research, and to encourage using recycled materials for construction industry.
5. It is recommended to use marble waste powder for maintaining roads.
6. After being aware of the importance of marble waste powder, all marble factories should be benefitted from it. They should pack and sell to maximize their income.
7. In this research, only some basic study of marble waste in hot mix asphalt concrete production is investigated, therefore, further investigations are required in the following areas:
   - Detail study of durability tests in situ to guarantee the performance of asphalt concrete mixture made by marble waste powder as a filler under the actual conditions of loads and environment.
   - More investigations should be done to measure the effects of the other bitumen type and content on the asphalt concrete mix with marble waste powder.

REFERENCES

Abebe Dinku (2002). Construction Materials Laboratory Manual. Addis Ababa university printing press, Addis Ababa, Ethiopia.

Abed and Sadoon (2005). The use of Sulaimania marble waste to improve the properties of hot mix Asphalt concrete. Anbar Journal for Engineering Sciences.

Abrar A. (2011). Using Marble waste powder in cement and concrete production. MSc Thesis, Addis Ababa university.

Anteneh T. (2014). Use of filler material in asphalt concrete mix. MSc Thesis proposal, Addis Ababa university.

Arshad, Shahid, Anwar and Shakier (2014). The waste utility in concrete, International Journal of Environmental research, ISSN 1735 – 6865.

Asmael (2005). Effects of mineral filler type and content on properties of Asphalt concrete mixes, Journal of Engineering.

Asphalt Institute (1997). Mix design for Asphalt concrete and other Hot - mix types (Manual Series - 2). 6th Edition, The Asphalt Institute.

Asphalt Institute (1998). Construction of Hot mix Asphalt pavements (Manual Series - 22). 2nd Edition, The Asphalt Institute.

Aukour and Mohamed I.Al – Qinna (2008). Marble production and environmental constrains, Jordan Journal of Earth and Environmental sciences, ISSN 1995 – 6681:11-21.

Berhanu A. (2001). Strength characteristics of Bituminous concrete with different Types of fillers

Bhole (2014).Study the behavior of Marble powder as supplementary cementitious material in concrete, J. Chavhan et al International Journal of engineering research, ISSN 2248 - 9622

Burdon (2004). Asphalt concrete, http://www.asphalt kingdom.com/what-is-asphalt.html.

Central Statistical Agency (2007). Report on large and medium scale manufacturing and electricity industries survey. Addis Ababa, Ethiopia.

Choudhary and Chandra (2005). Granite and Marble dusts as filler in Asphalt concrete, Indian Institute of Technology Roorkee, India.

Debashish, Mahabir and Prakash Giri (2014). Influence of Fly - ash as a filler in Bituminous mixes. ASPN Journal of Engineering and Applied Sciences, ISSN 1819 - 6608.

Ethiopian Marble Industry - Public Enterprise Profile, www. Ppesa. gov. et / Public Enterprise Profile. Aspx.

Ethiopian Road Authority. Pavement design manual (2001), volume 1, Addis Ababa, Ethiopia.

Ethiopian Road Authority (2009). Special provisions for standard Technical Specification. Maystebri - Shire Road upgrading project, Addis Ababa, Ethiopia.

European Asphalt Pavement Association (2015). Asphalt concrete, http:// www. eapa. Org /asphalt. php? c =78.

Fennis, Walraven, A.den uij (2009). The use of Particle Packing Models to Design Ecological Concrete, http://heron.tudelft. Nl/54-23/5.pdf.

Gammal, Ibrahim, A.Badr, A.Asker and Galad (2011). Health risk Assessment of Marble dust. Journal of Nature and Science. 9 (11):144 – 154.

Hameed and Sekar (2009). Properties of green concrete containing quarry rock dust and marble sludge powder as fine aggregate, ARPN Journal of Engineering and Applied Sciences.

Heldal and Walle (2001). Natural Stones in Ethiopia, Journal of Geological survey of Norway, ISSN 0800 – 3416.

Heldal and Walle (2002). Marble potential in Ethiopia, Journal of Geological Survey of Ethiopia.

Huseyin, Gurer, Sedat Cetin and Elmaci (2016). Investigation of Using granite sludge as filler in bituminous mixtures. Journal of Con.and bul. materials, Elsevier. 36 (2012): 430 – 436.

Millier (1931). Portland cement, en. Wikipedia. Org /wiki/ Portland cement.

Origlieri (1998). Marble stone, http://www.mineralzone.com/stones/marble.htm.

Peter (2005). Marble stone, http://geology.com/rocks/marble.htm.

Randy (2014). Asphalt concrete, https:// www.asphalt pavement.org/ index. php? option = com-content & view = article & bid = 21&Itemid = 41**.**

Sentayehu Z. (2011). Opportunities for dimension stone resource development in Ethiopia, Journal of Geological Survey.

Sevilkofteci, Niyaziogur kockal (2014). Using Marble wastes as fine aggregate in hot mix Asphalt production, Institute of research Engineers and Doctors.

Shahzada, Bashir Alam, Bilal, Mushtaq Zeb and Akbar (2016). Marble powders effect on permeability and mechanical properties of concrete, International Journal of Civil, Environmental and Structural Engineering.

Tanzania (2000). Laboratory Testing Manual.

Tarun (2005). Industry and Environment on the Sustainability of the Concrete http:// vmjohn. pcc. usp**.** Br /Arquivos/ On the Sustainability of the Concrete. Pdf.

Zemichael B. (2007). Effects of different types of filler materials on characteristics of Hot mix Asphalt concrete. MSc Thesis, Addis Ababa university, Ethiopia.

APPENDIX - A

Test results of Trial mix – 1 group one

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II	ERCC

STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS

Lab Number		Type of Asphalt	60 / 70
Type of Bituminous mixture	wearing course	Date Paved	
Bulk Specific gravity (Aggregate)	2.827	Station Paved	
Bulk Specific gravity (Mineral filler)	2.7	Sampled from	
Specific gravity of Asphalt	1.03	Date Molded	01 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893	No. of hour cured	30min.
Effective Specific gravity (Aggregate)	2.905	Date Tested	02 / 06 / 2015
Aggregate content,% by weight of total mixture	95.18	Stability correction, $Y = 0.002x^2 + 1.262x – 0.069$	

				Specification Limit
1.Asphalt, % by weight of mix	4.82			
2.Effective Asphalt content, %	3.88			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1242.7	1232.8	1247.8	
5.Mass in water, gm	753.1	745.2	758.3	
6.Mass of surface – dry in air, gm	1243.3	1233.1	1248.0	
7.Volume of specimen, cm^3	490.2	487.9	489.7	
8.Specific Gravity, Actual	2.535	2.527	2.548	
9.Specific Gravity, Actual, Average	2.537			
10.Maximum Specific Gravity	2.671			
11.Asphalt, % by volume	9.57			
12.Air Voids, %	5.03			3 – 7
13. Voids in mineral Aggregates, VMA (%)	14.6			13 – 16
14. Voids filled with Asphalt, VFA (%)	65.6			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	61.0	60.0	59.0	
16.Correlation Ratio	1.09	1.09	1.09	
17.Stability Measured, KN	8.28	8.07	8.49	
18.Stability Corrected, KN	11.46	11.17	11.76	
19.Stability Corrected Average, KN	11.46			9 – 18
20.Flow, Total distortion failure, mm	2.33	2.47	1.63	
21.Flow Average, mm	2.14			2 – 4

APPENDIX - B

Test results of Trial mix – 1 group Two

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II	ERCC

STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS

Lab Number		Type of Asphalt	60 / 70
Type of Bituminous mixture	wearing course	Date Paved	
Bulk Specific gravity (Aggregate)	2.827	Station Paved	
Bulk Specific gravity (Mineral filler)	2.7	Sampled from	
Specific gravity of Asphalt	1.03	Date Molded	01 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893	No. of hour cured	30min.
Effective Specific gravity (Aggregate)	2.891	Date Tested	02 / 06 / 2015
Aggregate content,% by weight of total mixture	95.18	Stability Correction, $Y = 0.002x^2 + 1.262\ x - 0.069$	

				Specification Limit
1.Asphalt, % by weight of mix	4.82			
2.Effective Asphalt content, %	4.05			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1235.3	1240.2	1233.3	
5.Mass in water, gm	745.8	756.5	745.4	
6.Mass of surface – dry in air, gm	1236.3	1240.6	1234.0	
7.Volume of specimen, cm^3	490.5	484.1	488.6	
8.Specific Gravity, Actual	2.518	2.562	2.524	
9.Specific Gravity, Actual, Average	2.535			
10.Maximum Specific Gravity	2.659			
11.Asphalt, % by volume	10.0			
12.Air Voids, %	4.68			3 – 7
13. Voids in mineral Aggregates, VMA (%)	14.7			13 – 16
14. Voids filled with Asphalt, VFA (%)	68.0			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	61.0	59.0	60.0	
16.Correlation Ratio	1.09	1.09	1.09	
17.Stability Measured, KN	7.11	9.22	7.68	
18.Stability Corrected, KN	9.82	12.79	10.62	
19.Stability Corrected Average, KN	11.08			9 – 18
20.Flow, Total distortion failure, mm	2.21	1.72	2.16	
21.Flow Average, mm	2.03			2 – 4

APPENDIX - C

Test results of Trial mix – 1 group Three

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II	ERCC

STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS

Lab Number		Type of Asphalt	60 / 70
Type of Bituminous mixture	wearing course	Date Paved	
Bulk Specific gravity (Aggregate)	2.827	Station Paved	
Bulk Specific gravity (Mineral filler)	2.7	Sampled from	
Specific gravity of Asphalt	1.03	Date Molded	03 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893	No. of hour cured	30min.
Effective Specific gravity (Aggregate)	2.851	Date Tested	04 / 06 / 2015
Aggregate content,% by weight of total mixture	95.18	Stability correction, $Y = 0.002x^2 + 1.262x - 0.069$	

				Specification Limit
1.Asphalt, % by weight of mix	4.82			;
2.Effective Asphalt content, %	4.53			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1233.7	1240.8	1232.6	
5.Mass in water, gm	732.8	749.4	749.2	
6.Mass of surface – dry in air, gm	1234.9	1241.4	1233.0	
7.Volume of specimen, cm^3	502.1	492.0	483.8	
8.Specific Gravity, Actual	2.457	2.522	2.548	
9.Specific Gravity, Actual, Average	2.509			
10.Maximum Specific Gravity	2.627			
11.Asphalt, % by volume	11.0			
12.Air Voids, %	4.50			3 – 7
13. Voids in mineral Aggregates, VMA (%)	15.5			13 – 16
14. Voids filled with Asphalt, VFA (%)	71.0			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	62.0	62.0	61.0	
16.Correlation Ratio	1.04	1.09	1.09	
17.Stability Measured, KN	6.90	8.00	8.38	
18.Stability Corrected, KN	9.08	11.07	11.61	
19.Stability Corrected Average, KN	10.59			9 – 18
20.Flow, Total distortion failure, mm	2.18	2.32	2.03	
21.Flow Average, mm	2.18			2 – 4

APPENDIX - D

Test results of Trial mix – 1 group Four

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II			ERCC
STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS				
Lab Number				Type of Asphalt 60 / 70
Type of Bituminous mixture	wearing course			Date Paved
Bulk Specific gravity (Aggregate)	2.827			Station Paved
Bulk Specific gravity (Mineral filler)	2.7			Sampled from
Specific gravity of Asphalt	1.03			Date Molded 03 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893			No. of hour cured 30min.
Effective Specific gravity (Aggregate)	2.862			Date Tested 04 / 06 / 2015
Aggregate content,% by weight of total mixture	95.18			Stability correction, $Y = 0.002x^2 + 1.262x - 0.069$
				Specification Limit
1.Asphalt, % by weight of mix	4.82			
2.Effective Asphalt content, %	4.40			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1230.0	1238.8	1240.5	
5.Mass in water, gm	748.0	753.3	741.6	
6.Mass of surface – dry in air, gm	1230.6	1239.0	1241.2	
7.Volume of specimen, cm^3	482.6	485.7	499.6	
8.Specific Gravity, Actual	2.549	2.551	2.483	
9.Specific Gravity, Actual, Average	2.527			
10.Maximum Specific Gravity	2.636			
11.Asphalt, % by volume	10.8			
12.Air Voids, %	4.11			3 – 7
13. Voids in mineral Aggregates, VMA (%)	14.9			13 – 16
14. Voids filled with Asphalt, VFA (%)	72.4			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	61.0	61.0	63.0	
16.Correlation Ratio	1.09	1.09	1.04	
17.Stability Measured, KN	8.92	9.57	6.37	
18.Stability Corrected, KN	12.37	13.29	8.37	
19.Stability Corrected Average, KN	11.34			9 – 18
20.Flow, Total distortion failure, mm	2.67	2.34	1.24	
21.Flow Average, mm	2.08			2 – 4

APPENDIX - E

Test results of Trial mix - 2 group One

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II			ERCC
STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS				
Lab Number				Type of Asphalt 60 / 70
Type of Bituminous mixture	wearing course			Date Paved
Bulk Specific gravity (Aggregate)	2.827			Station Paved
Bulk Specific gravity (Mineral filler)	2.7			Sampled from
Specific gravity of Asphalt	1.03			Date Molded 07 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893			No. of hour cured 30min.
Effective Specific gravity (Aggregate)	2.857			Date Tested 08 / 06 / 2015
Aggregate content,% by weight of total mixture	95.03			Stability correction, $Y = 0.002x^2 + 1.262x – 0.069$
				Specification Limit
1.Asphalt, % by weight of mix	4.97			
2.Effective Asphalt content, %	4.61			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1245.3	1241.7	1227.0	
5.Mass in water, gm	755.3	741.8	745.6	
6.Mass of surface – dry in air, gm	1245.9	1242.8	1227.7	
7.Volume of specimen, cm^3	490.6	501.0	482.1	
8.Specific Gravity, Actual	2.538	2.478	2.545	
9.Specific Gravity, Actual, Average	2.521			
10.Maximum Specific Gravity	2.625			
11.Asphalt, % by volume	11.3			
12.Air Voids, %	3.98			3 – 7
13. Voids in mineral Aggregates, VMA (%)	15.3			13 – 16
14. Voids filled with Asphalt, VFA (%)	73.9			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	59.0	60.0	61.0	
16.Correlation Ratio	1.09	1.04	1.14	
17.Stability Measured, KN	9.74	7.21	8.03	
18.Stability Corrected, KN	13.53	9.50	11.62	
19.Stability Corrected Average, KN	11.55			9 – 18
20.Flow, Total distortion failure, mm	2.87	2.07	2.28	
21.Flow Average, mm	2.41			2 – 4

APPENDIX - F

Test results of Trial mix - 2 group Two

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II	ERCC

STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS

Lab Number		Type of Asphalt	60 / 70
Type of Bituminous mixture	wearing course	Date Paved	
Bulk Specific gravity (Aggregate)	2.827	Station Paved	
Bulk Specific gravity (Mineral filler)	2.7	Sampled from	
Specific gravity of Asphalt	1.03	Date Molded	07 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893	No. of hour cured	30min.
Effective Specific gravity (Aggregate)	2.859	Date Tested	08 / 06 / 2015
Aggregate content,% by weight of total mixture	95.03	Stability correction, $Y = 0.002x^2 + 1.262x – 0.069$	

				Specification Limit
1.Asphalt, % by weight of mix	4.97			
2.Effective Asphalt content, %	4.58			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1247.0	1223.6	1251.0	
5.Mass in water, gm	757.8	742,0	757.7	
6.Mass of surface – dry in air, gm	1248.3	1224.3	1251.5	
7.Volume of specimen, cm^3	490.5	482.3	493.8	
8.Specific Gravity, Actual	2.542	2.537	2.533	
9.Specific Gravity, Actual, Average	2.538			
10.Maximum Specific Gravity	2.627			
11.Asphalt, % by volume	11.3			
12.Air Voids, %	3.41			3 – 7
13. Voids in mineral Aggregates, VMA (%)	14.7			13 – 16
14. Voids filled with Asphalt, VFA (%)	76.8			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	59.0	59.0	60.0	
16.Correlation Ratio	1.09	1.14	1.09	
17.Stability Measured, KN	8.33	7.92	8.82	
18.Stability Corrected, KN	11.53	11.46	12.23	
19.Stability Corrected Average, KN	11.74			9 – 18
20.Flow, Total distortion failure, mm	1,76	1.97	2.17	
21.Flow Average, mm	1.97			2 – 4

APPENDIX - G

Test results of Trial mix - 2 group Three

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II	ERCC

STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS

Lab Number		Type of Asphalt	60 / 70
Type of Bituminous mixture	wearing course	Date Paved	
Bulk Specific gravity (Aggregate)	2.827	Station Paved	
Bulk Specific gravity (Mineral filler)	2.7	Sampled from	
Specific gravity of Asphalt	1.03	Date Molded	11 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893	No. of hour cured	30min.
Effective Specific gravity (Aggregate)	2.868	Date Tested	12 / 06 / 2015
Aggregate content,% by weight of total mixture	95.03	Stability correction, $Y = 0.002x^2 + 1.262x – 0.069$	

				Specification Limit
1.Asphalt, % by weight of mix	4.97			
2.Effective Asphalt content, %	4.47			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1245.4	1247.3	1243.0	
5.Mass in water, gm	758.6	747.0	742.3	
6.Mass of surface – dry in air, gm	1247.0	1248.1	1244.4	
7.Volume of specimen, cm^3	488.4	501.1	502.1	
8.Specific Gravity, Actual	2.550	2.489	2.476	
9.Specific Gravity, Actual, Average	2.505			
10.Maximum Specific Gravity	2.635			
11.Asphalt, % by volume	10.9			
12.Air Voids, %	4.93			3 – 7
13. Voids in mineral Aggregates, VMA (%)	15.8			13 – 16
14. Voids filled with Asphalt, VFA (%)	68.8			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	60.0	61.0	61.0	
16.Correlation Ratio	1.09	1.04	1.04	
17.Stability Measured, KN	8.57	5.99	6.19	
18.Stability Corrected, KN	11.87	7.86	8.13	
19.Stability Corrected Average, KN	9.29			9 – 18
20.Flow, Total distortion failure, mm	2.55	2.10	2.09	
21.Flow Average, mm	2.25			2 – 4

APPENDIX - H

Test results of Trial mix - 2 group Four

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II			ERCC
STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS				
Lab Number				Type of Asphalt 60 / 70
Type of Bituminous mixture	wearing course			Date Paved
Bulk Specific gravity (Aggregate)	2.827			Station Paved
Bulk Specific gravity (Mineral filler)	2.7			Sampled from
Specific gravity of Asphalt	1.03			Date Molded 11 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893			No. of hour cured 30min.
Effective Specific gravity (Aggregate)	2.912			Date Tested 12 / 06 / 2015
Aggregate content, % by weight of total mixture	95.03			Stability correction, $Y = 0.002x^2 + 1.262x - 0.069$
				Specification Limit
1.Asphalt, % by weight of mix	4.97			
2.Effective Asphalt content, %	3.96			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1249.0	1244.0	1240.9	
5.Mass in water, gm	755.8	747.0	744.3	
6.Mass of surface – dry in air, gm	1249.5	1244.5	1241.7	
7.Volume of specimen, cm^3	493.7	497.5	497.4	
8.Specific Gravity, Actual	2.530	2.501	2.495	
9.Specific Gravity, Actual, Average	2.508			
10.Maximum Specific Gravity	2.669			
11.Asphalt, % by volume	9.6			
12.Air Voids, %	6.03			3 – 7
13. Voids in mineral Aggregates, VMA (%)	15.7			13 – 16
14. Voids filled with Asphalt, VFA (%)	61.5			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	60.0	60.0	61.0	
16.Correlation Ratio	1.09	1.04	1.04	
17.Stability Measured, KN	8.86	7.19	7.04	
18.Stability Corrected, KN	12.28	9.47	9.27	
19.Stability Corrected Average, KN	10.34			9 – 18
20.Flow, Total distortion failure, mm	1.95	2.13	1.64	
21.Flow Average, mm	1.91			2 – 4

APPENDIX - I

Test results of Trial mix - 3

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II			ERCC
STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS				
Lab Number				Type of Asphalt 60 / 70
Type of Bituminous mixture	wearing course			Date Paved
Bulk Specific gravity (Aggregate)	2.827			Station Paved
Bulk Specific gravity (Mineral filler)	2.7			Sampled from
Specific gravity of Asphalt	1.03			Date Molded 27 / 05 / 2015
Apparent Specific gravity(Aggregate)	2.893			No. of hour cured 30min.
Effective Specific gravity (Aggregate)	2.935			Date Tested 28 / 05 / 2015
Aggregate content, % by weight of total mixture	94.88			Stability correction, $Y = 0.002x^2 + 1.262x – 0.069$
				Specification Limit
1.Asphalt, % by weight of mix	5.12			
2.Effective Asphalt content, %	4.68			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1242.4	1220.5	1203.6	
5.Mass in water, gm	754.2	743.5	752.0	
6.Mass of surface – dry in air, gm	1259.3	1238.0	1237.9	
7.Volume of specimen, cm^3	505.1	494.5	485.9	
8.Specific Gravity, Actual	2.460	2.468	2.477	
9.Specific Gravity, Actual, Average	2.468			
10.Maximum Specific Gravity	2.567			
11.Asphalt, % by volume	9.2			
12.Air Voids, %	3.85			3 – 7
13. Voids in mineral Aggregates, VMA (%)	17.2			13 – 16
14. Voids filled with Asphalt, VFA (%)	77.54			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	66.0	65.0	65.0	
16.Correlation Ratio	1.04	1.09	1.09	
17.Stability Measured, KN	4.87	7.78	4.75	
18.Stability Corrected, KN	6.37	10.76	6.51	
19.Stability Corrected Average, KN	7.88			9 – 18
20.Flow, Total distortion failure, mm	2.88	3.00	2.79	
21.Flow Average, mm	2.89			2 – 4

APPENDIX - J

Test results of Trial mix - 4

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II	ERCC

STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS

Lab Number		Type of Asphalt	60 / 70
Type of Bituminous mixture	wearing course	Date Paved	
Bulk Specific gravity (Aggregate)	2.827	Station Paved	
Bulk Specific gravity (Mineral filler)	2.7	Sampled from	
Specific gravity of Asphalt	1.03	Date Molded	16 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893	No. of hour cured	30min.
Effective Specific gravity (Aggregate)	2.938	Date Tested	17 / 06 / 2015
Aggregate content, % by weight of total mixture	95.18	Stability correction, $Y = 0.002x^2 + 1.262x – 0.069$	

				Specification Limit
1.Asphalt, % by weight of mix	4.82			
2.Effective Asphalt content, %	3.51			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1236.6	1235.1	1232.4	
5.Mass in water, gm	757.6	757.0	755.6	
6.Mass of surface – dry in air, gm	1237.2	1235.4	1233.1	
7.Volume of specimen, cm^3	479.6	478.4	477.5	
8.Specific Gravity, Actual	2.578	2.582	2.581	
9.Specific Gravity, Actual, Average	2.580			
10.Maximum Specific Gravity	2.697			
11.Asphalt, % by volume	8.8			
12.Air Voids, %	4.32			3 – 7
13. Voids in mineral Aggregates, VMA (%)	13.1			13 – 16
14. Voids filled with Asphalt, VFA (%)	67.1			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	58.0	58.0	57.0	
16.Correlation Ratio	1.14	1.14	1.14	
17.Stability Measured, KN	12.94	10.39	9.78	
18.Stability Corrected, KN	18.92	15.12	14.21	
19.Stability Corrected Average, KN	16.08			9 – 18
20.Flow, Total distortion failure, mm	3.31	2.20	2.82	
21.Flow Average, mm	2.78			2 – 4

APPENDIX - K

Test results of Trial mix - 5

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II	ERCC

STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS

Lab Number		Type of Asphalt	60 / 70
Type of Bituminous mixture	wearing course	Date Paved	
Bulk Specific gravity (Aggregate)	2.827	Station Paved	
Bulk Specific gravity (Mineral filler)	2.7	Sampled from	
Specific gravity of Asphalt	1.03	Date Molded	16 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893	No. of hour cured	30min.
Effective Specific gravity (Aggregate)	2.914	Date Tested	17 / 06 / 2015
Aggregate content, % by weight of total mixture	95.18	Stability correction, $Y = 0.002x^2 + 1.262x – 0.069$	

				Specification Limit
1.Asphalt, % by weight of mix	4.82			
2.Effective Asphalt content, %	3.79			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1231.6	1235.9	1230.7	
5.Mass in water, gm	757.2	762.0	755.1	
6.Mass of surface – dry in air, gm	1232.4	1236.4	1231.4	
7.Volume of specimen, cm^3	475.2	474.4	476.3	
8.Specific Gravity, Actual	2.592	2.605	2.584	
9.Specific Gravity, Actual, Average	2.594			
10.Maximum Specific Gravity	2.678			
11.Asphalt, % by volume	9.5			
12.Air Voids, %	3.15			3 – 7
13. Voids in mineral Aggregates, VMA (%)	12.7			13 – 16
14. Voids filled with Asphalt, VFA (%)	75.2			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	58.0	57.0	57.0	
16.Correlation Ratio	1.14	1.14	1.14	
17.Stability Measured, KN	8.68	10.03	9.69	
18.Stability Corrected, KN	12.58	14.58	14.08	
19.Stability Corrected Average, KN	13.75			9 – 18
20.Flow, Total distortion failure, mm	1.64	2.26	3.02	
21.Flow Average, mm	2.31			2 – 4

APPENDIX - L

Test results of Trial mix - 6

SHELADIA in Association with EIE & HITCON	MAYTSEBRI – SHIRE ROAD UPGRADING PROJECT Contract No. II	ERCC

STABILITY TEST OF BITUMINOUS MIXTURES USING MARSHAL APPARATUS

Lab Number		Type of Asphalt	60 / 70
Type of Bituminous mixture	wearing course	Date Paved	
Bulk Specific gravity (Aggregate)	2.827	Station Paved	
Bulk Specific gravity (Mineral filler)	2.7	Sampled from	
Specific gravity of Asphalt	1.03	Date Molded	17 / 06 / 2015
Apparent Specific gravity(Aggregate)	2.893	No. of hour cured	30min.
Effective Specific gravity (Aggregate)	2.838	Date Tested	18 / 06 / 2015
Aggregate content, % by weight of total mixture	95.18	Stability correction, $Y = 0.002x^2 + 1.262x – 0.069$	

				Specification Limit
1.Asphalt, % by weight of mix	4.82			
2.Effective Asphalt content, %	4.68			
3.Specimen identification	1	2	3	
4.Mass in air, gm	1245.4	1235.9	1232.5	
5.Mass in water, gm	748.1	759.4	755.9	
6.Mass of surface – dry in air, gm	1246.9	1236.7	1233.1	
7.Volume of specimen, cm^3	498.8	477.3	477.2	
8.Specific Gravity, Actual	2.497	2.589	2.583	
9.Specific Gravity, Actual, Average	2.556			
10.Maximum Specific Gravity	2.617			
11.Asphalt, % by volume	11.6			
12.Air Voids, %	2.31			3 – 7
13. Voids in mineral Aggregates, VMA (%)	13.9			13 – 16
14. Voids filled with Asphalt, VFA (%)	83.4			65 – 80
Marshal Soaked for 30 Min.				
15.Thickness of Specimen, mm	61.0	58.0	57.0	
16.Correlation Ratio	1.04	1.14	1.14	
17.Stability Measured, KN	7.25	8.69	9.13	
18.Stability Corrected, KN	9.55	12.60	13.25	
19.Stability Corrected Average, KN	11.80			9 – 18
20.Flow, Total distortion failure, mm	1.71	3.71	3.15	
21.Flow Average, mm	2.86			2 – 4

APPENDIX - M

Laboratory quality test results for Coarse and Fine Aggregate

APPENDIX - N

Laboratory test results of bituminous binder (Asphalt)

APPENDIX - O

Laboratory test results of Bulk specific gravity of mineral filler, apparent specific gravity of Aggregate and Bulk specific gravity of Aggregate

APPENDIX - P

Photo Attachments

Photo 1: Gradation of aggregate determined by a sieve analysis of Aggregate samples.

Photo 2: Weighing aggregates for trial mixes.

Photo 3: Heating aggregate and bituminous binder in oven.

Photo 4: Adding bituminous binder to the heated aggregate and weigh.

Photo 5: Mixing of hot mix asphalt concrete.

Photo 6: Measuring the temperature of hot mix asphalt concrete mix.

Photo 7: Placing of hot mix asphalt concrete into mold.

Photo 8: Hot mix asphalt concrete specimen during compaction.

Photo 9: Spreading the uncompacted hot mix asphalt concrete specimen.

Photo 10: Quartering the spreading hot mix asphalt concrete specimen arranged for test.

Photo 11: Hot mix asphalt concrete specimen arranged for test.

Photo 12: Measuring the thickness of hot mix asphalt concrete specimen.

Photo 13: Weighting the hot mix asphalt concrete specimen mass in air (dry in water).

Photo 14: Weighting the hot mix asphalt concrete specimen mass in water.

Photo 15: Weighting the hot mix asphalt concrete specimen mass of surface – dry in air

Photo 16: Shaking the sample.

Photo 17: Fill water in pecnometer jar.

Photo 18: Weighting mass of pecnometer jar with water and sample.

Photo 19: Immersing hot mix asphalt concrete specimen in water bath.

Photo 20: Arranging hot mix asphalt concrete specimen for Marshall Stability and Flow test.

Photo 21: Marble waste powder pits at Saba Dimensional stone factory site (Adwa).

Photo 22: Marble waste powder pits at Saba Dimensional stone factory site (Adwa).